99-8

AIRCRAFT ACCIDENT INVESTIGATION REPORT

JAPAN AIRLINES FLIGHT 706
McDONNELL DOUGLAS MD-11, JA8580
OVER SHIMA PENINSULA, JAPAN
JUNE 8, 1997

December 17, 1999

AIRCRAFT ACCIDENT INVESTIGATION COMMISSION

MINISTRY OF TRANSPORT, JAPAN

ATTENTION

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

This report on the accident of McDonnell Douglas MD-11 of Japan Airlines, JA8580, has been prepared based upon the investigation carried out by the Aircraft Accident Investigation Commission in accordance with Annex 13 to the Convention on International Civil Aviation and Article 20 of the Aircraft Accident Investigation Commission Establishment Law of Japan.

Yasuhiko Aihara
Chairman,
Aircraft Accident Investigation Commission

Abbreviations used in this report are as follows:

ACARS : Aircraft Communications Addressing and Reporting System
ACT−RIB : Actuator−Right Inboard
ADAS : Auxiliary Data Acquisition System
AFS : Automatic Flight System
AIP : Aeronautical Information Publication
AOM : Aircraft Operating Manual
AP or A/P : Autopilot
APO : Airport
APP : Approach
CAS : Computed Air Speed
CCP : Control Column Position
CG : Center of Gravity
CHG : Change
CHPY : Choppy
CMD : Command
COM : Command
CRT : Cathode Ray Tube
CVR : Cockpit Voice Recorder
DAMP : Damper
DEP : Departure
DFDR : Digital Flight Data Recorder
DME : Distance Measuring Equipment
ECRM : Elevator Command Response Monitor
EL : Elevator
ELEV : Elevator
FCC : Flight Control Computer
FCOM : Flight Crew Operating Manual
FCP : Flight Control Panel
FL : Flight Level
FMA : Flight Mode Annunciator
FNL : Final
IAS : Indicated Air Speed
INC : In cloud
INFO : Information
INV : Invalid
JST : Japan Standard Time
KIAS : Knots Indicated Air Speed
LRU : Line Replaceable Unit
LSAS : Longitudinal Stability Augumentation System
LT : Light

ＭＡＣ　　　：Mean Aerodynamic Chord
ＭＯＮ　　　：Monitor
Ｎ　　　　　：North
ＮＧＯ　　　：Nagoya
ｎｍ　　　　：Nautical Mile
ＯＣＮＬ　　：Occasionally
ＯＭ　　　　：Operations Manual
ＰＡ　　　　：Passenger Address
ＰＲＤ　　　：Pitch Rate Damper
ＱＮＨ　　　：Pressure Setting to Indicate Elevation above Mean Sea Level
ＳＡＴ　　　：Static Air Temperature
ＳＥＬ　ＡＬＴ：Selected Altitude
Ｔ　　　　　：Thousand
ＴＡＳ　　　：True Air Speed
ＴＵＲＢ　　：Turbulence
ＶＥＬ　　　：Velocity
ＶＯＲ　　　：VHF Omni-directional Radio Range
ＶＯＲＴＡＣ：VHF Omni-directional Radio Range Tactical Air Navigation
V_{MO}　　　：Maximum Operating Limit Speed
Ｖ／Ｓ　　　：Vertical Speed
ＷＮＤ　　　：Wind
ＷＸ　　　　：Weather
ＸＭＣ　　　：Kowa VORTAC

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1. PROCESS AND PROGRESS OF THE ACCIDENT INVESTIGATION

1.1 Summary of the Accident

On June 8, 1997, a McDonnell Douglas MD-11 of Japan Airlines (JAL), registration JA8580, which departed Hong Kong International Airport as a scheduled international passenger flight 706 en route to Nagoya International Airport and had been in cruise flight in accordance with its flight plan, experienced abrupt pitch oscillations while in descent for landing to Nagoya International Airport at an altitude of approximately 17,000 ft (about 5,100 m) over Shima peninsula at around 1948 Japan Standard Time (JST).

Of the 180 persons - 169 passengers and 11 crew members - aboard the aircraft, a passenger and 3 cabin attendants were seriously injured, and 4 passengers and 4 cabin attendants received minor injuries.

The passenger cabin interior was slightly damaged by the pitch oscillations.

1.2 Outline of the Accident Investigation

1.2.1 Organization of the Investigation

1.2.1.1 On June 9, 1997, the Aircraft Accident Investigation Commission assigned an investigator-in-charge and three investigators. Subsequently, one further investigator was assigned.

1.2.1.2 The following three technical advisers were appointed for the investigation of specialized matters with respect to the accident.

(1) For analysis of flight performance: (Date of appointment; June 23, 1997)
Toshio Bando, Director, Flight Experiment Division, National Aerospace Laboratory, Science and Technology Agency.

and

Naoki Matayoshi, Turbulence Laboratory of Flight Experiment Division, National Aerospace Laboratory, Science and Technology Agency.

(2) For analysis of meteorology: (Date of appointment; March 20, 1998) Doctor Takashi Harada, Department of Geographical Science, Japanese Self Defence Academy.

1.2.1.3 Accredited representatives from the U.S.A, the state of design and manufacture of the aircraft, participated in the factual investigation.

1.2.2 Implementation of the Investigation

The investigation proceeded as follows.

June 9 ～ June 11, 1997 On-site investigation and interview

June 17, 1997 Interview

June 9, 1997 ～ July 30, 1998 DFDR/ADAS retrieval and analysis

July 20 ～ July 28, 1997

Visit to the U.S.A by technical adviser and investigators

February 11 ～ February 15, 1998

Visit to the U.S.A by technical adviser and investigators

March 17, 1998 Interview

1.2.3 Hearings from Persons relevant to the Cause of the Accident

Hearings were conducted.

1.2.4 Reporting and Publication

On September 5, 1997, based upon the factual investigation up to that date, the AAIC submitted the interim report on this accident with "Proposals" on safety issues that should be improved for the present to the Minister for Transport and those were made public on the same day.

On March 5, 1999, in line with some accidents/incidents involving aircraft in operation which experienced upsets causing persons on board to sustain injuries, the AAIC made an additional "Proposals" on the promotion of fastening seat belts at all times in operating aircraft.

(Refer to Appendix 11-1)

2 FACTUAL INFORMATION

2.1 Flight History

2.1.1 Flight History based on the DFDR Data , ATC Radio Communications, etc.

On June 8, 1997, a McDonnell Douglas MD-11, JA8580, departed Hong Kong International Airport at 0738 UTC (1638 JST; hereinafter all times shown are JST unless otherwise specified) as Japan Airlines flight 706.

The flight plan (FPL) of the flight submitted to the Airport Information Center of Hong Kong International Airport was as follows:

FLIGHT RULE: IFR, DEPARTURE AERODROME: Hong Kong, CRUISE: 480 kt (True Airspeed), LEVEL: FL370, ROUTE: G581 – TAPOP – A597 – KEC – V52 – XMC – KCC, DESTINATION AERODROME: Nagoya, TOTAL EET: 3 hrs 27 mins, ALTERNATE AERODROME: Kansai

According to the DFDR data and ATC radio communications, the subsequent flight history was summarized as follows.

The aircraft reached a cruise altitude of FL370 at around 1659.

The aircraft, which had been in cruise flight at FL370, was instructed by the Tokyo Area Control Center (ACC) to descend to FL290 at around 1934 and initiated its descent.

At around 1941, the aircraft requested the Tokyo ACC "Tokyo Control, JAL 706, Approaching FL290, Request further descent". Responding to the request, the Tokyo ACC instructed the aircraft "JAL 706, Stand by", and the aircraft acknowledged the instruction.

At around 1942, the aircraft reached and leveled off at FL290.

At around 1944, the Tokyo ACC instructed the aircraft to change the radio frequency to 125.7 MHz. The aircraft changed the frequency and requested the Tokyo ACC again to make a further descent from FL290. In response to the request, the Tokyo ACC cleared the aircraft "JAL 706, Descend and maintain 9,000, Cross XMC (Kowa VORTAC)".

At around 1945, the aircraft commenced descending.

At 1945:52, the aircraft crossed an altitude of 26,000 ft and then crossed 25,000 ft at 1946:10.

The Computed Airspeed (CAS) began to increase halfway through the aircraft's descending and exceeded the V_{MO} (365 KIAS) for a while, followed by reaching a maximum airspeed of 368 knots at 1948:25.

At 1948:26, the autopilot (AP) was disconnected at an altitude of 16,700 feet. Immediately thereafter the aircraft abruptly pitched up and subsequently five large amplitude pitch oscillations lasted over the next 15 seconds. The vertical acceleration (G) around the center of gravity of the aircraft reached positive peak value of + 2.8G and negative peak value of – 0.5G.

The abrupt pitch oscillations caused passengers and flight attendants to receive various injuries.

At 1948:41, the AP was reengaged, around which the pitch oscillations were dampened out.

At 1950:57, the Tokyo ACC instructed the aircraft to contact Nagoya Approach Control. Responding to the instruction, the aircraft began to contact Nagoya Approach Control.

At 2014, the aircraft landed at Nagoya Airport.

The accident occurred at an altitude of 17,000 ft over Shima peninsula at approximately 1948. (Refer to attached Figure 1 and Photograph 1～4)

2.1.2 Statement of the Captain about the Flight History

The following are outlines of the statement on the flight history made by the Captain.

"After departing Hong Kong International Airport, the aircraft continued airborne at a cruise altitude of FL370 via Route G581 en route to Nagoya airport.

"There were little vibrations in the cruise flight.

"Subsequently the aircraft was cleared from the Tokyo ACC to descend to FL290 and commenced descending per the clearance. During the descent, I deemed that the AP was attempting to follow the settings selected on the Flight Control Panel (FCP). Immediately before reaching FL290, since I requested the Tokyo ACC a further descent but was instructed to stand by and maintain FL290 for another 10～15 nautical miles, I reduced the airspeed to 260 knots, and after I had been restricted to maintain the altitude (FL290) for a while, the aircraft was cleared 'Descend and cross XMC 9000 ft' Note 1 from the Tokyo ACC and commenced a further descent.

"Because the aircraft had to descend with a considerable high descent rate in order to comply with the ATC clearance, I moved the IAS/MACH select knob on the FCP panel to select an Indicated Airspeed (IAS) of 350 KIAS.

"I assumed that I would have adequately coped with the above ATC clearance for descent, despite being not easy for me to comply with, during the descent phase of accelerating the airspeed to 350 knots from 260 knots which had been reduced.

"I deemed that although the rate of descent in the case of usual descent with 300 knots is 2,200～2,500 ft/min, the rate of descent in the accident flight was about 3,500 ft/min in steady state and marked about 4,400 ft/min during acceleration because of the aircraft's descending with a considerable high sink rate.

"Although winds in an upper air were relatively calm and clouds in the radar returns were not sighted, I turned on the seat belt sign earlier at an altitude of 25,000 ft or 26,000 ft because the aircraft had an information on turbulence (Refer to section

2.6.4 and 2.10.1 (1) in details) and was performing a high speed descent.

"Since I had an information on a turbulence which was predicted at an altitude of 15,000~20,000 ft, assuming that the turbulence would have existed halfway between the altitudes, I switched on the seat belt sign with about three minutes' margin.

"I felt little vibrations during the descent.

"While the aircraft was passing an altitude of approximately FL170, the IAS showed an abrupt increasing tendency and the first officer called 'Caution Speed'. At this point of time, I moved the pitch thumbwheel on the Flight Control Panel (FCP) in an attempt to lower the rate of descent by making the aircraft pitch nose up. However, since there appeared no 'bug' of presenting a decrease in the descent rate on an instrument in the cockpit, I, worrying about the IAS overshooting, pulled the speed brakes to the 1/3 position. Whereas, the instrument displayed that the IAS still continued increasing. Therefore, just as I attempted to pull the speed brakes toward the 2/3 position, the aircraft was in overspeed and at almost the same time the autopilot disengaged followed by an abrupt pitch up, and subsequently a couple of large amplitude of pitch oscillations occurred.[Note 2] I felt the situation as if I had ridden on the waves, not as encountering a burble of turbulence.

"I was not sure whether the pitch oscillations resulted from that the AP was disconnected by turbulence or that the AP itself merely disconnected.

"Rather it might be right that I had a relatively shallow impression of what I felt vibrations or encountered an external disturbance.

"I had no idea about the reason of the pitch oscillations because I was in the situation that I could not rule out the possibility of the aircraft's anomaly.

"I felt the pitch oscillations lasted several times for one or two seconds. Immediately thereafter, just as I engaged the AP No.1 as saying 'Autoflight!', the aircraft recovered its stabilized flight and continued descending.

"After being radar vectored along a longer route than usual (a wide pattern; because of a request from the cabin that the cabin attendants need some more minutes in preparation for landing) from the navigational fix 'XMC', the aircraft landed on runway 16 of Nagoya Airport by VOR/DME-A approach.

"Although alerts of 'LSAS CHANNEL FAIL' and 'YAW DAMP CHANNEL FAIL'[Note 3] were displayed in the cockpit, the aircraft continued airborne because there was no anomaly of the flight control system. (Refer to "Note 2" below)

According to the Captain's statement about the MD-11's AP, he knows that the MD-11 AP will be disconnected by an excessive G load but is not familiar with the AP disconnection caused by what extent of force exerted on the control column.

Note 1: The following is an actual ATC communication excerpted from the ATC transcriptions.

"JAL706 Descend and maintain 9,000 ft, Cross XMC 9,000ft. QNH2982."

Note 2: In a Captain Report submitted to the Minister for Transport in accordance with Article 76 of Japan's Civil Aeronautics Law on June 12, 1997, he stated that "......extended the speed brakes. At this moment the over speed warning sounded and, at almost the same time, the AP disconnected. Subsequently, a couple of large amplitude of pitch oscillations occurred."

Note 3: A "LSAS CHANNEL FAIL" and a "YAW DAMP CHANNEL FAIL" are alerts displayed on the CRT in the cockpit that means "The LSAS has failed" and "The yaw damper channel has failed", respectively.

2.2 Injuries to Persons

One passenger and three cabin attendants were seriously injured, and four passengers and four cabin attendants sustained minor injuries.

(Note) It is stated in Chapter1 of Annex 13 to the ICAO convention that an injury resulting in death within thirty days of an accident is classified as a fatal injury and an injury requiring hospitalization for more than 48 hours, commencing within seven days from the date the injury was received is classified as a serious injury.

2.3 Damage to Aircraft

2.3.1 Extent of Damage

The passenger cabin interior was slightly damaged.

2.3.2 Interior Damage Description

(1) The cover of an exit indicator lamp for the L4 door was fractured.
(2) The cover of an emergency exit indicator lamp near the L4 door was fractured
(3) The ceiling support rods and brackets, which supported the ceiling panels in the aft cabin, were found damaged.
(4) The damage to several portions of the ceiling panels in the aft galley were found.

2.3.3 Discrepancies of Equipment written in the Flight Log after the Accident

According to the flight log of the aircraft, discrepancies of equipment that occurred during the flight were summarized as follows.

(1) Overspeed warning was activated during descent.
(2) LSAS and yaw damper channel faults illuminated during the final approach.

(3) Vertical acceleration exceeded the limitation.

(4) The DFDF and CVR are required to be replaced due to encountering turbulence.

(5) There were three items regarding damages to a seat table lock and door entry light.

Results of checks and repairs performed as corrective actions to the above discrepancies were made the entries in the flight log. However, there was no description pertaining to the discrepancy which contributed to the cause of the accident.

2.4 Crew Information

2.4.1 Flight Crew

Captain: Male, aged 46	
Airline Transport Pilot License	No.[redacted] issued July 11, 1989
Type Rating	
Airplane multiengine land	Issued April 10, 1973
Douglas DC-8	Issued April 3, 1981
Boeing 747	Issued July 5, 1985
Douglas MD-11	Issued March 28, 1994
Class 1 Airman Medical Certificate	No. [redacted]
Term of validity	Until June 24, 1997
Total flight time	9,133 hours 41 minutes
Flight time during the previous 30 days	28 hours 58 minutes
Total flight time on MD-11	1,299 hours 20 minutes
Flight time during the previous 30 days	28 hours 58 minutes
Issuance of Captain Certificate on MD-11	March 18, 1994
Route Qualification of Captain for the route	March 14, 1995
The latest renewal	March 29, 1997
First Officer: Male, aged 33	
Commercial Pilot License	No.[redacted] issued November 8, 1989
Type Rating	
Airplane multiengine land	Issued May 28, 1990
Boeing 747	Issued April 16, 1993
Douglas MD-11	Issued March 29, 1995
Instrument Rating	No.5357
	Issued August 8, 1990
Class 1 Airman Medical Certificate	No. [redacted]
Term of validity	Until October 8, 1997

Total flight time	2,509 hours 41 minutes
Flight time during the previous 30 days	53 hours 39 minutes
Total flight time on MD-11	874 hours 49 minutes
Flight time during the previous 30 days	53 hours 39 minutes
Issuance of First officer Certificate on MD-11	March 23, 1995

2.4.2 Cabin Attendants

A. Chief Purser (Male, aged 54)

Position at the time of accident	L1 door
Date of occupation	April 8, 1966
Total flight time	16,270 hours

B. Cabin Attendant (Female, aged 43)

Position at the time of accident	L4 door
Date of occupation	January 19, 1975
Total flight time	13,813 hours

C. Cabin Attendant (Female, aged 43)

Position at the time of accident	L2 door
Date of occupation	February 1, 1975
Total flight time	16,165 hours

D. Cabin Attendant (Female, aged 33)

Position at the time of accident	R1 door
Date of occupation	June 13, 1984
Total flight time	8,170 hours

E. Cabin Attendant (Female, aged 34)

Position at the time of accident	L3 door
Date of occupation	July 25, 1985
Total flight time	8,764 hours

F. Cabin Attendant (Female, aged 33)

Position at the time of accident	R4 door
Date of occupation	June 1, 1987
Total flight time	3,699 hours

G. Cabin Attendant (Female, aged 26)

Position at the time of accident	R2 door
Date of occupation	December 1, 1993
Total flight time	2,415 hours

H. Cabin Attendant (Male, aged 30)

Position at the time of accident	R3 door
Date of occupation	December 28, 1987

Total flight time	7,205 hours

I. Cabin Attendant (Female, aged 29)

Position at the time of accident	R2 door
Date of occupation	February 18, 1991
Total flight time	4,909 hours

2.5 Aircraft Information

2.5.1 The Aircraft

Type	Douglas MD-11
Serial No.	48571
Date of manufacture	August 4, 1993
Certificate of Airworthiness	93-020
Term of validity	Until valid date of JAL's Maintenance Manual
Total aircraft flight time	9,383 hours 01 minutes
Aircraft flight time after scheduled maintenance for "A" check performed on June 3, 1997	37 hours 26 minutes

2.5.2 The Engines

Type Pratt & Whitney model PW4460

	No.1	No.2	No.3
Serial No.	733754	733775	733706
Date of manufacture	January 28, 1994	March 1, 1995	May 26, 1994
Total time in service	1,865 hrs 41 min.	261 hrs 06 min.	7,757 hrs 52 min.
Date of installation	November 9, 1996	May 7, 1997	November 25, 1996

2.5.3 Weight and Center of Gravity

The weight of the aircraft at the time of the accident is estimated to have been approximately 414,500 lbs, with its center of gravity at 29.5% MAC, both being within allowable limits (maximum takeoff weight being 602,500 lbs, with the allowable range of center of gravity corresponding to the estimated weight at the time of accident of 10.0% to 34.0% MAC).

2.5.4 Fuel and Lubricating Oil

The fuel on board was JET A-1. The lubricating oil was MJO-Ⅱ.

2.6 Meteorological Information

2.6.1 Synoptic Weather

According to the Meteorological Agency's announcement, the synoptic weather in the vicinity of Owase City, Mie Prefecture between 1700 and 2100JST on June 8, 1997 was as follows:

According to a Surface Weather Analysis at 2100JST on June 8, 1997, a low pressure area, which centers west coast of Kyusyu island, is proceeding to east-north-east at a speed of 30 kilometers per hours. A warm front extending from the low pressure area stretches offshore south of Shikoku island.

According to a cloud image (infrared and visible rays) from the geostationary meteorological satellite and a nephanalysis information, a convective cloud developed near the front was getting active at some places in the west of Kinki region.

Clouds, which prevailed over Chita peninsula but were not developed, were not observed in the weather radar returns. According to a regional weather obsevation facility, more than 1 mm of rain was not observed in the vicinity of Owase city between 1700 and 2100 JST.

A wind speed was lower than 3 meters per second on the earth's surface. According to upper air observation at 2100 JST which was provided by the Shionomisaki weather observation facility, the wind at an altitude of 500 hectopascal layer was 35 knots out of the south-west. No noticeable shears in the wind direction and speed, however, were observed in the upper and lower layers of 500 hectopascal.

The Tsu district Weather Service Center issued an advisory for thunderstorm, gale, high waves and dense fog at 2100 JST on June 8 in the south region of Mie prefecture, including Owase city.

(Refer to attached Figure 4～8)

2.6.2 Energy-Per-Unit Mass Diagram Observed after the Accident

According to an energy-per-unit mass diagram (hereinafter referred to as "Emagram") observed at Shionomisaki and Hamamatsu at 2100JST after the accident, there existed a stratification (atmospheric temperature inversions) at an altitude of about 11,000 ft over Shionomisaki, about 20,000 ft over Hamamatsu and other several altitudes. (Refer to attached Figure 9 and 10)

It is considered that this kind of stratification is occasionally accompanied by a vertical windshear [NOTE].

NOTE: The vertical windshear means variations in horizontal winds' speed/direction which blow along vertical atmospheric layer.

2.6.3 Aviation Weather Observation

The aviation weather observations around the time of the accident, as provided by the Aviation Weather Center at Nagoya Airport, were as follows:

Time of observation (JST)	1900 JST	1930 JST	2000 JST
Wind direction	150°	150°	140°
Wind speed	14 knots	12 konts	15 knots
Visibility (kilometers)	above 10 km	above 10 km	above 10 km
Cloud			
Cloud amount	1/8	1/8	1/8
Cloud form	Cumulus	Cumulus	Cumulus
Height of cloud base	3,000 ft	3,000 ft	3,000 ft
Cloud amount	3/8	3/8	3/8
Cloud form	Altocumulus	Altocumulus	Altocumulus
Height of cloud base	12,000 ft	12,000 ft	12,000 ft
Cloud amount	8/8	8/8	8/8
Cloud form	Altostratus	Altostratus	Altostratus
Height of cloud base	15,000 ft	15,000 ft	15,000 ft
Temperature/dew point:	22℃/15℃	21℃/16℃	21℃/16℃
Atmospheric pressure (QNH)	29.82 inHg	29.82 inHg	29.82 inHg

2.6.4 ACARS Information

Before the accident, the aircraft received an ACARS information at 1920, including an information on the existence of light turbulence. The ACARS information was organized by Japan Airlines based on information reported from other JAL aircraft which had flown ahead of the aircraft near the accident area. (Refer to Note below)

Note: The received ACARS information by the aircraft were as follows;

NGO APO INFO AS OF 08JUN/1900I

APP/DEP AREA

NORTH/EAST.....18T-35T INC

16T-20T CHPY OCNL LT TURB

24T N 33T-35T CHPY

WEST....................22T-18T CHPY DUE WND CHG
SOUTH................22T-15T LT TURB DUE WIND
VEL CHG
WX OUTLOOK................CLOUDY
OTHER..............................FNL ROUGH

2.6.5 ADAS Recordings related to Weather Conditions

A Static Air Temperature (SAT) and Wind Direction/Speed recorded on the ADAS (Auxiliary Data Acquisition System) of the aircraft during a time zone before and after the accident are shown in Appendix 1-3 as plotted data.

2.7 Communications

All communications between the aircraft and Tokyo ACC (125.7 MHz) during the time zone before initiating the descent until the occurrence of the accident were satisfactory.

2.8 Information on CVR, DFDR, etc

The aircraft was equipped with a Fairchild model A100A CVR (Serial No. 52525) and an AlliedSignal model UFDR 980-4110-DXUS DFDR (Serial No. 3701). Both were removed from the aircraft after landing.

2.8.1 CVR Recording

Voices and sounds in the cockpit are stored on a 30 minute endless loop magnetic tape recording medium until a CVR stops operating, recording over the oldest data after 30 minutes. However, the CVR recorded voices and sounds pertinent to the maintenance that was carried out after the aircraft parked at a ramp after landing. Therefore, since the recordings near the accident were erased because the time has elapsed more than 30 minutes after the accident occurred, no CVR information pertinent to the accident was available.

Additionally, the JAL's "Operations Manual" contained the following descriptions;

"when a PIC (Pilot In Command) makes a decision that the CVR recordings should be kept after cutting off the engines following finishing (or aborting) a flight, he or she should take actions to immediately cut a circuit breaker to stop the CVR operation. In this case, the PIC are required to write down the CVR stoppage in the flight log and to request a maintenance person who is line maintenance qualified to replace the CVR."

2.8.2 DFDR and ADAS Recordings

Data on 262 parameters were recorded on the DFDR from about the time when the aircraft departed a ramp at Hong Kong International Airport until the aircraft blocked-in at Nagoya Airport.

The times recorded on the DFDR, which were sampled from the built-in master clock of the aircraft, were determined by matching VHF keying discrete data on the DFDR with the radio transmissions on the ATC recorder to evaluate the expected unreliability in the times.

Plots of the DFDR and ADAS major parameters during the time zone before and after the accident occurred are attached as Appendix 1.

Of the Parameters used for analysis in this accident investigation report, Control Column Position (CCP), Control Column Force (CWS-PITCH representing a force exerted on the Captain side's control column), Ground Speed (GS), Rate of Descent and Static Air Temperature (SAT) were obtained from the ADAS because these parameters were not included in the DFDR parameter configuration.

In addition, parameters regarding Wind Speed/Direction and SEL ALT (an altitude selected by moving the IAS/MACH select knob on the FCP) recorded on the ADAS were used for analysis together with these parameters recorded on the DFDR which were roughly sampled once per minute.

Since data recorded on the ADAS were delayed compared to data recorded on the DFDR, the time base for the ADAS data was matched to that for the DFDR data by means of comparing the time difference between the Vertical Gs which were recorded 8 times per second on the ADAS and the DFDR, respectively. In addition, one second (one subframe) ADAS data at 1948:31 was lost due to the occurrence of an "ADAS data shedding".

Further, based on the evidence that each parameter's time delay on a data bus from the sensor to the time when the data is recorded on the DFDR or the ADAS can vary from zero to some seconds, the major parameters attached as Appendix 1 were plotted as a function of time which was actually recorded on each word slot on the subframe (one second) of the DFDR and the ADAS because of the uncertainty as to when the parameters were actually sampled at the sensors. However, times mentioned in Chapter 3 "Analysis" of this report are expressed as a function of the subframe time (omitting fractions less than one second) of each parameter recorded on the DFDR/ADAS.

Further, in a detailed analysis conducted in Appendix 2 through 4, the aforementioned time uncertainty was corrected by averaging variations in a time delay on the data bus. (Refer to Appendix 2)

2.9 Medical Information

2.9.1 Injuries to Passengers and Crew Members

Of the 180 persons on board – 169 passengers, 11 crew members –, a passenger and 3 cabin attendants were seriously injured, and 4 passengers and 4 cabin attendants sustained minor injuries.

2.9.2 Details of the Injuries

Details of the extent and portions of injuries to the one passenger and three cabin attendants who were seriously injured and their statements are as follows.

(1) Passenger, male aged 48 (Walking in the cabin away from his seat 58D, which the seat number is based on his statement)

The extent and portion of injuries : Fracture of the transverse process of the 1st～4th lumbar vertebrae.

Outlines of the statement : He encountered the sudden upsets while he was walking in the aisle near the seat 47C. He was lifted to the ceiling and dropped to the floor at which he struck the armrest.

(2) Cabin attendant, female aged 30 (Working in the aft galley)

The extent and portion of injuries : Fracture of the public bone, Open fracture of the left thumb, Bruise on the face

Outlines of the statement : She was suddenly lifted while she was organizing the passenger service goods in the aft galley and seemed to struck someplace, and thereafter she came to her senses by other cabin attendant's voices.

(3) Cabin attendant, female aged 43 (Working in the aft galley)

The extent and portion of injuries : Fracture of the pelvis, Burst fracture of lumbar vertebra 1 and Fracture of the right radial head (caputradii).

Outlines of the statement : She brought receipts of sales in the cabin to another cabin attendant in the forward galley, and shortly after she returned to the aft galley she first felt a severe lateral shock and then was pushed up by the floor as if the floor had fallen out though she gripped an iron bar nearby.

(4) Cabin attendant, female aged 33 (Working in the aft galley)

The extent and portion of injuries : Cerebral contusion, Fracture of the pelvis

Outlines of the statement : She was not available for statement because she has been hospitalized in the condition of "No visitors".

Details of the extent and portions of injuries to the four passengers and four cabin attendants who sustained minor injuries and their statements are as follows

(1) Passenger, female aged 42 (Using washroom away from her seat 29K, which the seat number is based on the JAL operator's records)

The extent and portion of injuries : Bruise of the left leg and the left ankle joint

Outlines of the statement : Just as she adjusted her dress after using washroom, the aircraft was suddenly shaken severely. She was lifted, then dropped to the floor and fell down.

(2) Passenger, male aged 36 (Seated in seat 61D, which the seat number is based on his statement)

The extent and portion of injuries : Sprain of the thoracic and lumber vertebrae

Outlines of the statement : He was resting in his seat with the seat belt not tightened when a severe vibration suddenly occurred. When he was lifted, the seat belt cut into his stomach.

(3) Passenger, male aged 52 (After moving to a window-side seat from seat 63D, which the seat number is based on the JAL operator's records)

The extent and portion of injuries : Lumber bruise, back ache and whiplash

Outlines of the statement : After moving to a window-side seat, he was resting in his seat with the seat belt not fastened when a violent vibration suddenly occurred. He was jumped from the seat and had his head struck the ceiling and then dropped to the floor at which he struck the armrest.

(4) Passenger, male aged 49 (On the way back to seat 64E, which the seat number is based on the JAL operator's records)

The extent and portion of injuries : Lacerated wound of the left earlobe

Outlines of the statement : On the way back to his seat after using the washroom a violent vibration suddenly occurred. He was lifted, had his back struck the ceiling and then was struck against the floor.

(5) Cabin attendant, female aged 43 (working in the forward galley)

The extent and portion of injuries : Rupture of the ligament(s) of the left ankle joint

Outlines of the statement : While she was organizing the sales receipts of duty-free goods standing in the forward galley, she suddenly fell down as if she were pressed against the floor.

(6) Cabin attendant, female aged 33 (working in the forward galley)

The extent and portion of injuries : Bruise on the head, Impaired visual acuity

Outlines of the statement : While she was clearing up files for sales of duty-free goods in the forward galley, she was suddenly pressed against the floor and fell down. It was the situation that she could hardly keep on standing.

(7) Cabin attendant, female aged 29 (working in the forward galley)

The extent and portion of injuries : Sprain of the left ankle

Outlines of the statement : While she was working in the forward galley, she was suddenly pressed against the floor

(8) Cabin attendant, female aged 34 (working in the forward galley)

The extent and portion of injuries : Lumber ache

Outlines of the statement : While she was working in the forward galley, she was suddenly pressed against the floor

2.10 Information on Rescue Activities

2.10.1 Situation in the Cabin before and after the accident

The following are outlines of the statements obtained from the Captain, cabin attendants and passengers regarding the situation in the cabin before and after the accident occurred.

(1) The Captain's Statements

"Prior to departing Hong Kong International Airport, I had the first officer made a pre-departure briefing to the cabin attendants. The briefing included the seat belt sign in such a way that the cabin attendants were instructed to sit down and fasten their seat belts immediately whenever the seat belt sign was switched on because of the predicted turbulence during the descent and to get the Captain's permission if there is a situation in which they can not fasten their seat belts.

"In addition to the above instruction, I repeated that the cabin attendants should immediately sit down without exception whenever the seat belt sign is on during a flight phase of climb, cruise and descent and that the seat belt sign is switched on only when a turbulence to an extent that unrestrained persons might be injured is anticipated, and so on.

"Moreover, I added that if a cabin attendant receives requests from passengers who want to leave their seats for using a washroom and so forth during the ON indication of the seat belt sign, the cabin attendant first should inform the cockpit of this. "Approximately 20 minutes prior to initiating a descent from FL370, the aircraft received an ACARS information including the existence of some light turbulence at an altitude between 22,000 ft and 15,000 ft and rough air along a final approach path to Nagoya Airport.

"I informed the cabin attendants of the ACARS information as well as a predicted time of turbulence and instructed them to finish their duties in the cabin before the aircraft commenced descending and to prepare for being able to sit down whenever the seat belt sign was switched on. (Refer to "Note1" below)

"Even though I have not usually been reported from the cabin about whether fastening the seat belts was completed after the seat belt sign was switched on, I believed that everybody in the cabin would have fastened the seat belt because the pre-departure briefing had been made.

"As I had monitored communications among the cabin attendants through the PA system, I realized that there seemed to have been some injuries in the cabin after the pitch upsets had occurred, and asked the Chief Purser (C/P) 'Did someone receive injuries in the cabin?'. I also asked 'Didn't the injured persons fasten their seat belts ?', but was not answered.

"Subsequently, the C/P came in to the cockpit and reported the states of injuries sustained by some passengers and cabin attendants and the necessity of doctor.

"When I told him that the aircraft would land in about 10 minutes, the CP gave me his opinion 'We need time to clear up the scattered things, if not, there may be some danger of the things being moved by shocks at the time of the aircraft landing.' So I thought that a 10 minutes holding was needed. But, soon after, as I was informed by the CP that the cabin attendants finished clearing up in the cabin and were ready for landing, I did not actually perform the 10 minutes holding.

"Judging from the CP's report, I took the state of the injuries as a degree that it was all right only to request the necessity of doctor. Additionally, judging from vibrations felt in the cockpit and the request for 10 minutes holding from the CP, I did not recognize that the injuries were as serious as I had to declare the emergency.

"Since I perceived the necessity of doctor, I had the first officer requested through the company radio communications but we were answered that doctor was not stationed right now. So the first officer finally requested arrangements for dispatching the ambulance(s). (Refer to "Note 2" below)

"Since the aircraft was already in the critical phase for landing at Nagoya Airport, it was extremely busy in the cockpit and we had to concentrate on controlling the aircraft, so we decided to leave treatments for the injured to the cabin attendants. This was the situation in which we could hardly make further reports on the injuries to the ground.

"I understood that the JAL ground staff and rescue workers were supposed to enter the aircraft to make arrangements for carrying the injured out of the cabin.

"After the aircraft blocked-in, we shut off the engines and completed a parking-checklist and, thereafter, when I proceeded to the cabin to take a look at the situation, I heard that people out here were talking about some delays in carrying the injured even though the ambulance seemed to have already arrived. So I asked them 'Please carry the injured as soon as you can'.

(Note 1) Of the Captain's statement, the paragraph "Approximately 20 minutes prior to initiating a descent from FL370, ...and instructed them to finish their duties in the cabin before the aircraft commenced descending and to prepare for being able to sit down whenever the seat belt sign was switched on." was based on the report submitted to the Minister for Transport by him after the accident. In addition to this, he expressed his opinion as follows in a later date.

"It was about 5 minutes before receiving an ACARS information on turbulence and about 25 minutes before initiating a descent that I instructed the cabin attendants to finish their duties in the cabin and to prepare for being able to sit down whenever the seat belt sign was on. And then, I was informed by a cabin attendant that they finished service and almost finished their duties in the cabin. When I received the ACARS information, I repeatedly advised them of an anticipated time of turbulence and instructed them to sit down immediately after an ON indication of the seat belt sign.

(Note 2) The first officer stated about the extent of injuries such as "I did not deem that the injured were in critical conditions such as unconsciousness."

He also outlined the request for doctor through the company radio communication as follows.

"I recalled that the Captain ordered me to ask the JAL Nagoya Airport branch office to call a doctor to the ship-side. So I requested through the company radio communication for calling the doctor to the ship-side because the aircraft's upsets during descent caused the cabin attendants to sustain injuries.

"Responding to my request, we were answered, 'Doctors are not stationed right now. How about ambulance(s)?' I recalled that because the Captain said to me, 'It will be all right only to request ambulance(s)', so I requested arrangement for dispatching ambulance(s) to the ship-side.

(2) The Statements of Chief Purser and other Cabin Attendants.

(The following outlines were composed mainly of the CP's statements with other cabin attendant's statements combined)

Prior to departing Hong Kong International Airport, the flight crew gave the cabin attendants a pre-flight briefing, in which they were instructed the following, "You should finish up the works in the cabin earlier because there might be a turbulence during the climb after the takeoff, in cruise flight over Okinawa island and during the descent toward Nagoya Airport. When the seat belt sign is on, be seated and have your seat belts fastened without exception. If you have to leave your position, get the Captain's permission." They were also given an instruction such that if there are passengers who are going to leave their seats for using a washroom and so on during the ON indication of the seat belt sign, they should ask the passengers to be patient or get the Captain's permission if the passengers can not stand it.

Since the seat belt sign came on several minutes prior to the occurrence of a violent upset, the cabin attendants walked around in the cabin to check whether passengers buckled their seat belts and at the same time a cabin attendant made an announcement over the PA system, "please fasten your seat belts and refrain from using the washroom" in Japanese and English. A PA announcement in Chinese is usually made by a (Hong Kong based) Chinese cabin attendant who is responsible for the announcement following an announcement in English, but violent pitch upsets lasted over about 30 seconds with no announcement in Chinese. As the upset was over, the CP contacted the aft galley by a phone placed at L2 door in an attempt to know the situation in the rear cabin but did not receive any response from there.

After a while, a passenger in the rear cabin proceeded to the forward galley and informed the CP of "some cabin attendants collapsed on the floor in the rear cabin." He hurried along the L-side aisle to the rear cabin to confirm the situations in the aft galley that had been informed. The middle cabin was calm, but as he proceeded to the rear cabin, blankets, pillows, magazines and so on were scattered on the floor.

On the floor at the close aisle between R4 and L4 door, three cabin attendants collapsed bleeding from their heads and/or faces. The CP called out to them, but they hardly responded with groans and so on, and two mealcarts toppled over the floor with the doors opened, from which foods, juice and so on were scattered.

More specifically, 11 mealcarts were equipped in the aft galley. Of the two mealcarts which jumped out of the stowed positions, one completely toppled over the floor and another was on the verge of toppling. All of the mealcarts were assumed to have been stowed in their positions but could not be confirmed whether those had been locked.

Judging from the situations, the CP called the cabin attendants who positioned near the L2 and R2 doors by a phone placed at the L4 door to come to the aft galley for assistance if they could. While he was calling, he was informed from someone in the rear cabin that passengers were injured. He went there and called out to two injured passengers and provided them with first-aid treatment.

The CP ordered the cabin attendants coming from the forward cabin for assistance to give first-aid treatments to the injured cabin attendants and stow the scattered galley containers and other things because the aircraft was in the critical phase of landing.

The CP recalled it would have taken five to ten minutes until he grasped the situation in the aft galley and rear cabin and provided first-aid treatment.

Subsequently, the CP reported the states of injured passengers and cabin attendants to the Captain via the PA system. At the same time, since he thought an arrangement for ambulance would be needed, he requested the Captain about this. Then, the CP proceeded to the cockpit confirming the situation in the whole cabin with a loud voice.

In the cockpit, the CP reported the states of injured passengers and cabin attendants as well as the situation in the rear cabin and aft galley to the captain in person. He was informed by the Captain that the aircraft was estimated to land at Nagoya Airport in 10 minutes (ETA : 2010 JST). But judging that the 10 minutes was not sufficient for the cabin attendants to check cabin security for landing, he requested the Captain that they needed another 10 minute or so before landing. The Captain acknowledged the request.

After that, the CP minimized his talks to the Captain because he thought the Captain could have grasped the situation in the rear cabin and aft galley by information he had given so far.

The CP did not make an announcement to see if there were doctors or nurses among the passengers because the aircraft was able to land at Nagoya Airport soon after the cabin safety check for landing was completed and he had already requested the Captain the arrangement for ambulances.

After the aircraft landed at Nagoya Airport and blocked-in, the CP opened the L2 door and looked for the ambulances. But the ambulances did not arrive yet and he thought "Not arrive yet? Incredible!"

Further more, some cabin attendants stated that the seat belt sign was lit at around 1945 (25 minutes before the aircraft arrived Nagoya Airport) or a couple of minutes prior to the occurrence of the violent upsets.

Cabin attendants, who did not fasten their seat belts at the time of the accident, stated that they were unable to fasten their seat belts until they cleared up files for sales of duty-free goods and so on or that they were standing in the galley after confirming the passenger's seat belts.

According to the statement of a cabin attendant who helped another cabin attendant clear up service goods for passengers in the aft galley, she was commanded by the CP to harry up one minute before the seat belt sign was lit.

Additionally, there was statement of a cabin attendant that she built a protective barrier for the injured cabin attendant who fell down on the floor by putting blankets and pillows against the toppled mealcarts and sat in the jump-seat to support the injured cabin attendant's head by her thighs for preparing the landing.

(3) The Statements of Passengers

Statements gathered from passengers are summarized as follows;

① A passenger in the forward cabin

"The flight had been smooth without noticeable vibrations until the accident occurred after the aircraft had departed Hong Kong.

"A sudden upset occurred while I was resting in my seat with the seat belt fastened.

"I recall the upsets like those "I felt a repeated up and down (two or three times) as if I had ridden on the waves", but the atmosphere around me was relatively calm partly because the forward cabin was not crowded.

"After the aircraft landed at Nagoya Airport, I realized that some people had been injured in the rear cabin.

② A passenger in the middle cabin

"The flight had been smooth until the accident occurred after the aircraft had departed Hong Kong. Since an announcement for fastening the seat belt was made 4 to 5 minutes prior to the occurrence of the accident, I fastened the seat belt.

"Subsequently I felt the upset once such that the aircraft rapidly descended (about 20 seconds) and then ascended (5 to 10 seconds).

"During the upsets, I felt as if I had ridden a roller coaster and perceived higher sense (acceleration) than that during the takeoff. I felt as if I were lifted, but I was held by the fastened seat belt.

"The cabin attendants were working in the galley.

"A person sitting next to me vomited because he appeared to became sick. Documents, brackets, pillows and so on were scattered around us.

"I recognized that bags and belongings were scattered and some people appeared to be injured in the rear cabin as wide as I could see.

"Nobody around me was injured.

"When the aircraft landed at Nagoya Airport, passengers around me were cheered with a storm of clapping.

③ Passengers in the rear cabin

"The flight had been smooth without a noticeable large vibration until the accident occurred after the aircraft had departed Hong Kong. Sudden upsets occurred at which my suit jacket put on next seat to me was thrown toward the front seat.

"Since my seat was situated near the washroom, I saw a male passenger came out of the washroom, fell down on the floor and some coins were scattered on the floor from his pocket. He was bleeding from his hand and seemed to complain of an ache in his hand. Then he stood up by himself and sat in next seat to me with the seat belt fastened. After the vibrations were quelled, he moved back to his seat.

Additionally, an another passenger stated the situation at the time of the accident as follows;

"The aircraft rapidly descended and then ascended. Lots of female passengers around me were screaming. Brackets, pillows, bags, juices and so on were scattered around my seat.

2.10.2 Activities on the Ground conducted by the JAL and the Organizations Involved

At around 1958, the JAL Nagoya Airport branch office (JAL branch office) was informed by the aircraft of the injuries with a request to have doctors stand by, but decided to arrange ambulances by consent with the aircraft because doctors were not stationed at Nagoya Airport.

According to the JAL branch office, subsequent radio communications from the JAL branch office to the aircraft were not made in accordance with the precedents[NOTE] because the aircraft was in final approach phase, and neither did the aircraft make any radio communication to the JAL branch office until it landed.

At 2005, the JAL branch office requested a local Fire Fighting Station (FFS; Nishikasugai east ward Fire Fighting Station) by a telephone call to dispatch an ambulance for the accident and to have it stand by in front of International Arrival Terminal of Nagoya Airport (usual standby position). According to the FFS, their age, sex and the extent of injuries of the injured persons were not available when the FFS received the telephone call, because the JAL branch office did not have any information on these.

Upon receiving the request, the FFS immediately dispatched an ambulance at 2006.

The ambulance arrived in front of the International Arrival Terminal at 2012 and stood by there.

The JAL branch office confirmed that the aircraft had landed at Nagaya Airport at 2014 and blocked-in at 2016.

At 2018, the supervisor of the JAL branch office, who was located by the aircraft, informed the office of the situation in the cabin and the number of the injured persons and asked the office to request the FFS to dispatch two more ambulances to the side of the aircraft.

At 2018, the ambulance, which had been standing by in front of the International Arrival Terminal, headed for the No.2 West Gate on a request by the JAL ground staff and arrived at the side of the aircraft at 2020.

Immediately after being informed of the number of the injured persons from company people affiliated to the JAL (the JAL personnel concerned), rescue workers entered the cabin and began to provide first-aid treatment. Because it was judged to be difficult to transfer the injured persons due to a narrow aisle in the cabin, after conferring between rescue workers and the JAL personnel concerned, they decided to have high-lift vehicles pulled over the exits on either side of the rear cabin, firstly move two of the seriously injured persons using a scoop stretcher to the ambulance and transfer them to Komaki Municipal Hospital.

Although receiving a request for other two ambulances from the JAL branch office at 2026, because there was only one ambulance left in the local FFS, the ambulance was dispatched at 2027 and arrived at the side of the aircraft at 2034.

At the time when the aircraft blocked-in, the JAL branch office had information on 11 injured – 3 passengers (one serious and two minor) and 8 cabin attendants (three serious and five minor), but one minor injured person was added to the number after a passenger declared his injury. Resultantly, the total number of injured was 12 (four serious and eight minor).

First ambulance, which recovered two serious injured persons, departed the aircraft at 2056 and arrived at the municipal hospital at 2104.

Second ambulance, which recovered other two serious injured persons and a minor injured person at 2105, arrived at the municipal hospital at 2113.

Two minor injured passengers, who were accompanied by JAL branch office's staff, were taken to the municipal hospital by a taxi.

(Note): The JAL's operations manual (OM) states that no ground staff should make company radio communications with aircraft in flight phase of departing, landing and final approach except as required for safety.

2.11 Tests and Research to Find Facts

2.11.1 Features of MD-11

(1) Structure and Flight Performance

① Structure (Refer to Figure 2)

Although basic structure of the MD-11 is similar to that of DC-10-40 which is one of the McDonnell Douglas[Note 1] previous model aircraft, its fuselage is stretched by 5.7 meters (223 inches) and its wing is extended by 1.3 meters (61.54 inches) by fitting a winglet to the tips of the wing.

The horizontal stabilizer is redesigned to reduce its size by 30 percent compared to that of the DC-10, resulted in a reduction in aerodynamic drag.

Unlike the DC-10, fuel cells built into the horizontal stabilizer, which are capable of containing approximately 2,000 gallons of fuel, are used as CG control Note 2 or fuel for long haul flight.

(Note 1): Although McDonnell Douglas became Boeing Douglas Products Division (DPD) in August, 1997, this report uses the name of McDonnell Douglas in Chapter 1 through Chapter 5.

(Note 2): The aft CG control provides the aircraft with its CG maintained as aft as possible by transferring fuel to cells built into the horizontal stabilizers from cells in the wing.

② Characteristics of Manual Control and Longitudinal Stability

The reduced area of the horizontal stabilizer and the aft CG were beneficial to improving the MD-11's flight performance, but included some problems of lower longitudinal stability characteristics especially in the high altitude cruise flight regime.

Thus, the MD-11 is equipped with a Longitudinal Stability Augmentation System (LSAS) to augment the longitudinal stability characteristics in manual flying.

The LSAS operates to hold the present pitch attitude when a force no more than 2 lbs is applied on the control column. The LSAS pitch attitude hold function is inhibited when a pilot applies a force in excess of 2 lbs to the control column, and the pitch attitude is manually changed by the pilot's control column inputs. Then, when the force is relaxed, the LSAS holds the new pitch attitude.

While the AP is being used, an elevator movement feedback is provided to the control column. But the control column does not get feedback on the elevator movement driven by the LSAS.

The LSAS software has been upgraded to add a Pitch Rate Damper (PRD) to enhance the longitudinal stability at high altitude, by which the control feeling of MD-11 has been improved.

A JAL in-house publication issued after the accident states that the control stability of MD-11 has been improved from the original by the addition of the PRD but care must be taken not to apply excessive input to the control column in the event of the AP disengagement especially at high altitude (refer to AOM 4-2-7).

Additionally, regarding the MD-11's manual control characteristics at high altitude, the JAL AOM (Aircraft Operating Manual) had described before the accident the note "Care must be taken not to over control" in a CAUTION item of the section "FLIGHT IN SEVERE TURBULENCE" and the note "When the autopilot is off, use minimum control inputs to fly attitude and allow the LSAS to maintain attitude by reducing pressure on the control column whenever possible" as a caution during the AP disengagement (i.e. manual control) in the same CAUTION item as above and the AOM Supplement. (Refer to Appendix 7)

These descriptions in the JAL AOM are fundamentally based on information provided by McDonnell Douglas such as the FCOM etc. (Refer to Appendix 6)

(2) MD-11 Autopilot System

Regarding the MD-11 AP, the JAL AOM previously described before the accident in section "FLIGHT IN SEVERE TURBULENCE" that a pilot should not override the AP with excessive force exerted on the control column, and this can cause the pilot to over control when the AP is disconnected. The similar descriptions were also included in the JAL's Pilot Training Guide. (Refer to Appendix 7 and 8)

These descriptions are also fundamentally based on the information provided by McDonnell Douglas.

Additionally, McDonnell Douglas presented a NOTE "Never Override the Autopilot" to operators at the MD-11 Flight Operations Seminar which was held before the accident. (Refer to Appendix 9)

On the other hand, the MD-11 AP has a system to be disengaged by the pilot's override.

According to McDonnell Douglas, the reasons for the autopilot override function on the MD-11 are to provide pilots with a backup disconnect function in the case of an autopilot hardover or where a pilots find that they are not able to disconnect the autopilot using the disconnect button.

"Override" means that the pilot applies a force to the control column with the AP engaged. The word "Override" used in this report has the same meaning as above.

In the case of Douglas DC-8 (previous-generation transport category aircraft older than MD-11), since the ability of computers was lower than that of current ones, when a pilot was not satisfied with AP's performance, he or she was able to supplement the low ability of the AP by overriding the AP with force exerted on the control column. Additionally, Boeing B747 is also a previous-generation transport category aircraft older than MD-11 and there is a system description explaining "Pilot's control wheel inputs can override the autopilot" in "System Study Guide" of the JAL's Pilot Training Guide for B747.

According to the McDonnell Douglas's viewpoint, however, in the case of the MD-11, it is fundamental that the pilot should leave an authority over controlling the aircraft to the AP when flying with the AP engaged, and, if the pilot would like to apply his/her manual force on the control column, proper procedures are as follows : the pilot should not apply force on the control column leaving the AP engaged, but the pilot should apply his/her control force on the control column only after switching to manual mode with the AP disengaged by AP disconnect switch. In this respect, characteristics of the MD-11 AP are different from that of the previous-generation aircraft.

In addition, the MD-11 AP has the following features;

① When flying in areas of abrupt changes in wind speed, the AP is designed with a time-lag in converging the airspeed on a selected target airspeed.

This is because the airspeed used by the AP (FCC airspeed) lags behind the indicated airspeed because the FCC airspeed is filtered to provide airspeed signal noise rejection in order to prevent autopilot and autothrottles from overreacting to variations in air-flow during turbulent flight.

② The MD-11 has an AP G-Control function.

This function has an speed limiting logic such that when the AP is engaged in the Flight Level Change (FLC) mode, the maneuvering G-limit associated with changes in the pitch attitude is maintained within a delta of 0.07G in the FCC during a normal flight regime and increases to 0.2G when the airspeed used in the FCC reaches V_{MO}-3 knots.

On the other hand, the maneuvering G-limit during a flight with the AP engaged in the Vertical Speed (V/S) mode is 0.2G. When a changeover from the FLC mode (G-limit of 0.07G) to the V/S mode occurs, the G-limit increases to 0.2G.

According to McDonnell Douglas, the reasons that the aforementioned maneuvering G-limit was incorporated are as follows;

a. to prevent hazards resulted from dynamic airmass.

b. to provide a function to prevent the aircraft from leveling off due to changes in the airspeed during descent or a function of acquiring an optimum descent rate with a constant airspeed.

c. to improve passengers' comfort.

The aforementioned maneuvering G-limit is not provided in manual flight.

2.11.2 Investigation of FCC and Flight Control System

As a result of the postaccident bench test examination, there was no evidence of a malfunction in the two FCCs and the right inboard (RIB) elevator's actuator which were removed from the aircraft.

The following are the investigation results concerning the contents of "Consolidated FCC Fault Report" recorded on the FCC.

(1) Activation of the Elevator Command Response Monitor (ECRM)

As a message indicating the situation near the time of the accident, a fault message “Failed Monitor : EL COM RESPONSE, Suspect LRU : ELEV ACT-RIB” was recorded on the “Consolidated FCC Fault Report” of the FCC-2 which was used by the AP No.2. This fault message indicated that the AP No.2 was disconnected by the ECRM of the FCC-2 which was monitoring the RIB elevator driven by the AP No.2 command. This is detailed as follows;

A left inboard (LIB) elevator is driven by the FCC-1 when the AP No.1 is engaged and the RIB elevator is driven by the FCC-2 when the AP No.2 is engaged. Movement of the RIB or LIB elevator will back drive the other three elevators through mechanical connections.

The AP will be disconnected by the ECRM when the difference between the actual position of the AP (FCC) driven elevator and the AP commanded position for that elevator is greater than a certain degrees-seconds, which will be attributed to a malfunction in the AP-servo system.

Additionally, the AP may be disconnected by the ECRM in the following case;

A force, which is manually exerted on the control column when the AP is engaged, is provided to actuators of all of the four elevators through control cables and linkages. Contrary to these movements, the AP servo drives an inboard elevator corresponding to the selected AP in an attempt to maintain the current pitch command, counteracting movement of the inboard elevator driven by a direct control column input. Resultantly, this causes a difference between the actual angle of the AP-servo driven inboard elevator and the AP commanded angle for the inboard elevator. The FCC ECRM function monitors the angular difference and duration.

The FCC ECRM function does not distinguish whether the difference was caused by a malfunction in the AP-servo system or whether it was caused by the pilot’s manual control column input, but, regardless of the causes, the function will disconnect the AP when the difference exceed a certain limit.

(2) Fault Massages regarding the LSAS and Yaw Damper

During the final approach, a fault message “Failed Monitor:LSAS CMD MON INV, Suspect LRU:FCC-1” was recorded on the “Consolidated FCC Fault Report” in the FCC-1. It was revealed from the fault message that an “Invalid” status was detected in the LSAS commands which were monitored by the FCC-1. This is outlined as follows;

Each FCC contains two LSAS channels, and the movements of four elevators are controlled by the four independent LSAS channels in the two FCCs, respectively. Each FCC monitors itself, and when a FCC detects a fault in a LSAS channel, the FCC disconnects its both LSAS channels. Thereafter, two elevators will be controlled by two LSAS channels in another FCC.

In the accident flight, the DFDR recorded fault messages on both LIB and

ROB LSAS channels at 2010:49 but showed no anomaly on both LOB and RIB LSAS channels.

Also, a fault message regarding the Yaw Damper which was recorded during the final approach shows an error occurred in either of two Yaw Damper channels (the two FCCs each have two Yaw Damper channels). In this case, the Yaw Damper is controlled by two channels in the properly operating FCC unless a particular action is taken by pilot. No information indicating an anomaly in the Yaw Damper channels was recorded on the DFDR, and no malfunction in the Yaw Damper system has been found since the accident. Therefore, it is considered to be likely that the malfunction in either of two Yaw Damper channels occurred over a very short period of time as the information was not recorded on the DFDR, during which the error channel went back to normal. However, the cause of the occurrence was not determined.

2.11.3 Pilot's Training and Reproduction of the Accident Flight by MD-11 Simulator

(1) Pilot's Training used by MD-11 Simulator

Before the accident, the JAL implemented simulator training on the MD-11's high altitude characteristics for all pilots of the JAL MD-11 fleet. The simulator training was to have the pilots conduct manual controls in a condition that the autopilot was disconnected by gusts of vertical direction and the aircraft pitch attitude significantly changed. According to information provided by the JAL, since a simulator training assumed that the aircraft's upsets occur resulting from the autopilot disengagement caused by the pilot's override is categorized as a prohibitive item, such training is not usually implemented.

(2) Reproduction of the aircraft's upsets and so on used in the MD-11 Simulator

Reproduction of the increase in the air speed prior to the occurrence of the accident and the abrupt pitch-up followed by the pitch oscillations was attempted using MD-11 flight simulators owned by McDonnell Douglas and the JAL. It was, however, impossible to completely reproduce those conditions of the accident flight.

It is estimated that the flight simulators, with data on wind speed not being incorporated into their software, were not able to reproduce variations in wind speed.

McDonnell Douglas subsequently conducted engineering flight simulator demonstrations to reproduce the aforementioned events using an engineering flight simulator with an approximation of wind activity near the time of the accident added to the simulator's software.

In these demonstrations conducted by McDonnell Douglas, the engineering flight simulator was able to activate the ECRM and produce the G forces as recorded on the DFDR. It was also able to generate the abrupt pitch-up followed by the pitch oscillations but unable to reproduce complete pitch oscillations with a single-frequency like those recorded on the DFDR of the accident flight.

Further, in terms of reproducing the flight situations at the time of the accident, the JAL's flight simulator was not able to reproduce the pitch oscillations. However, the JAL's flight simulator demonstrations subsequently reproduced periodic pitch oscillations by means of chasing pitch changes with the control column inputs.

The engineering flight simulator demonstrations at McDonnell Douglas with the same conditions experienced by the aircraft at the time of the accident except wind activity showed that approximately 50 pounds of control column force was required to activate the ECRM and produce the G force as recorded on the DFDR.

2.11.4 Examples of the Previous Accident / Incident of In-Flight Upsets involving MD-11

Refer to Appendix 5 concerning representative examples of accident/incident involving MD-11.

2.12 Other Relevant Information

2.12.1 Documents regarding the Definition of V_{MO}

Refer to Appendix 13 concerning documents with respect to the definition of the V_{MO}.

The V_{MO} is defined as "an operational limitation" or "a speed that pilots may not deliberately exceed.

If the airspeed exceeded the V_{MO}, the aircraft is required to receive a special inspection per the JAL and McDonnell Douglas maintenance manual after the flight.

2.12.2 The JAL In-house Requirements etc. with respect to fastening Seat Belt

The following are descriptions appeared in the JAL's OM at the time of the accident;

(1) concerning an announcement for passengers

"Before take-off and land, cabin attendants should require passengers to fasten their seat belts through a PA announcement or in person and check to see if they do so." and "Cabin attendants should make a PA announcement for passengers to fasten their seat belts when the seat belt sign is switched on during turbulent flight and so on and, further, repeatedly require them at appropriate intervals to do so in the case of a long time ON indication of the seat belt sign during flight."

(2) to cabin attendants

"when seat belt sign is lit, cabin attendants should take their jump seats with their seat belts fastened."

In addition, at the time of the issuance of a revision (as of December 15, 1991) to the JAL's OM including the above descriptions, a JAL in-house circular "Cabin Service Now No. 123" was issued by the JAL international cabin attendants department, domestic cabin attendants department and cabin services department in joint signature. In this circular, the object of the revision to the JAL's OM is outlined as follows:

(1) The seatbelt sign will be turned on as a "warning" of the upsets (that means a potential dangers to an extent that persons in the cabin would receive injuries unless they sit down with their seat belts fastened).

Cabin attendants are not allowed in principle to leave their seat during the ON indication of the seatbelt sign except as required for humanitarian reasons such as the care of the sick.

(2) When the seatbelt sign is switched on during turbulent flight, cabin attendants should require passengers to fasten their seat belts through a PA announcement, not a visual check.

Since the seatbelt sign is switched on with a meaning of "Warning", cabin attendants should in principle sit down after minimizing their safety measures in the cabin such as stowing hazardous things or guiding passengers who are waiting for a washroom back to their seats at the time of the ON indication of the seatbelt sign.

2.12.3 The JAL In-house Requirements regarding Details of Communication and Rescue Activity in the Event of Injuries

The JAL's OM did not clearly describe how to communicate information between company persons concerned in the event of injuries under the limitation of making contact with the cockpit during final approach regime.

Further, actions taken on the ground to the injured persons were included in the JAL's "International Passenger Manual", but details of rescue activity at Nagoya Airport were not specified.

2.12.4 Major Actions taken by the Manufacturer and the Operator before the Accident

Refer to Appendix 6 concerning major actions taken by manufacturer and airlines before the accident.

3 ANALYSIS

3.1 General

3.1.1 The flight crew (Captain and First Officer) had valid airmen proficiency certificates and valid airmen medical certificates.

3.1.2 The aircraft had a valid airworthiness certificate and was maintained and checked in accordance with applicable regulations.

3.1.3 Analysis of the weather condition

Based on the SAT (Static Atmosphere Temperature) data on the ADAS and the Emagram Chart observed at Shionomisaki and Hamamatsu after the accident, it is estimated that a stratification (atmospheric temperature inversions) existed near the flight route over Shima peninsula where the aircraft was passing at the time of the accident.

In addition, it is estimated, based on the ADAS data, that there existed a vertical windshear (refer to a NOTE in section 2.6.2) accompanied by variations in the wind direction/speed in the above region.

It is estimated that the above weather phenomenon (the stratification and the vertical windshear) resulted from a localized atmospheric agitation.

Appendix 3 shows changes in the wind speeds that the aircraft would have encountered in the above region, which was derived from calculating the difference between the Ground Speed and True Air Speed (TAS) of the aircraft on the DFDR/ADAS data in which the effects of changes in the aircraft attitude were corrected. As the result of the above calculation, it is estimated that the rates of changes in the wind speed sustained by the aircraft reached 1.7～2.8 knot per second. (Refer to Appendix 3)

3.2 Flight Sequence of the Aircraft until the time of the accident

Based on the recordings of the DFDR and ADAS, it is estimated that the flight sequence after the aircraft had departed Hong Kong International Airport until the time shortly after the accident occurred were as follows.

3.2.1 Flight Sequence after Takeoff until the Time when CAS exceeded 350 knots while in descending

It is estimated that the aircraft had continued an uneventful cruise flight at FL370 after taking off Hong Kong International Airport and commenced descending from the altitude at around 1934.

It is estimated that the aircraft, with the AP No.2 engaged, descended and leveled off at FL290 for a while and then, at 1944:59, initiated the further descent with the AP No.2 engaged in the Vertical Speed (V/S) mode, which was based on the changeover of the indications on the FMA. At this moment, the CAS indicated 262 knots.

It is estimated, based on the changeover of the indications on the FMA from 1945:09 through 1945:10, that the aircraft continued descending with the AP No.2 changed into the FLC mode during the time frame. At 1945:09, the level-off altitude of 9,000 ft was selected on the AP No.2.

Generally, when the AP is engaged in the FLC mode for descending, throttles are placed at the idle clamp positions by an autothrottle (A/T) command and the AP gets the aircraft to descend to a selected target altitude by changing the aircraft's pitch attitude to control the airspeed toward the target airspeed.

At 1945:58, it is estimated, based on the indications on the FMA, that the aircraft was descending with the AP No.2 engaged in the FLC mode, at which the level-off altitude of 9,000 ft and the airspeed of 350 KIAS were selected on the AP No.2.

It is estimated, based on the changeover of the indications on the FMA from 1946:35 through 1946:36, that the AP No.2 was changed into the V/S mode during the time frame. At 1946:35, the altitude of 23,700 ft and the CAS of 311knots were recorded on the DFDR.

At 1946:44, the rate of descent was -5,000 ft/min on the DFDR. This is considered to have resulted from the rate of descent of -5,000 ft/min selected on the AP No.2.

At 1947:08, the A/T was disconnected at an altitude of approximately 21,300 ft. Since then, the A/T had remained disconnected until 1948:40. All three of the Throttle Resolver Angle (TRA) which represents the engines' thrust stood at 38° (Idle Stop Position) at the time of the A/T disengagement and had remained at almost the same angle until 1948:26.

At 1947:16, the CAS increased to 339 knots, at which the rate of descent was -4,000 ft/min. This is also considered to have resulted from the rate of descent of -4,000 ft/min selected on the AP No.2.

It is estimated, based on the changeover of the indications on the FMA from 1947:27 through 1947:28, that the AP No.2 was changed into the FLC mode from the V/S mode at an altitude of about 20,000 ft and the aircraft continued descending.

Between 1947:45 and 1947:58, the CAS stabilized at approximately 350 knots, during which the rate of descent was ranging approximately from -3,000 ft/min to -3,100ft/min.

The CAS decreased to 344 knots between 1948:06 and 1948:07 but, thereafter, began to increase. The rate of descent presented an increasing tendency and was -4,200 ft/min at 1948:12, at which the CAS was 346 knots.

At 1948:15, the CAS reached 351 knots at an altitude of approximately 17,300 ft, exceeding the target airspeed (350 knots) which was selected on the AP No.2.

The pitch angle, which had been –4.6° at 1948:14, began to gradually change in the aircraft nose-up (ANU) direction.

Around which, it is estimated that the aircraft, which had continued to descend with the AP No.2 engaged in the FLC mode, already began to encounter the wind changes as detailed in Appendix 3-1.

3.2.2 Flight Sequence after CAS exceeded 350 knots until the time shortly after the accident

A CWS PITCH (parameter on the ADAS representing a force exerted on the Captain side's control column) began to noticeably increase in the ANU direction between 1948:15 and 1948:16, from around which the CCP also began to noticeably increase in the ANU direction. It is estimated that these events resulted from the Captain exerting backpressure on the control column to make the aircraft pitch-up in an attempt to arrest the increasing air speed. It is estimated that the AP resultantly turned out to be overridden. On the attached graph in Appendix 1-2, the movements of the CWS-PITCH appear to lag behind those of the CCP by approximately one second. The time lag is attributed to method of plotting each parameter in order of time (word slot) which is designated for each parameter in the subframe (one second) of the DFDR and the ADAS. An adoption of the above method of plotting parameters as mentioned in detail in Appendix 14 may present actual events in some cases but, in the case of the accident, brought about the time lag in the CWS-PITCH against the CCP. It is estimated that there was not eventually the above time lag between the CWS-PITCH and CCP at the sensors.

At 1948:16, the CAS reached 353 knots, around which the rate of descent became approximately -3,800 ft/min.

Even thereafter, the CAS continued to increase and reached 360 knots at an altitude of 17,000 ft at 1948:20, around which the rate of descent became approximately -3,000 ft/min.

At 1948:21, the speed brakes (Spoilers) began to deploy and then rapidly extended toward their full deflections from 1948:23 through 1948:25. During this time frame, values of the vertical G decreased despite the increase in the pitch angle. This is estimated to have been due to a combination of the AP's speed limiting logic, the aforementioned AP override and the speed brakes deployment.

The CAS continued to further increase and reached 366 knots at 1948:24 after exceeding the V_{MO} (365 knots), at which the rate of descent became –2,700 ft/min.

At 1948:25, the speed brakes reached approximately 27 degrees.

Values of the CWS PITCH (the Captain side control column force) saturated at 25 lbs in the ANU direction on the ADAS data between 1948:25 and 1948:26. It is estimated that ANU forces greater than the 25 lbs maximum readable force on the ADAS data were actually exerted on the control column during this time frame. In addition, the CCP increased in the ANU direction to about 4 degrees at 1948:25.

Data indicating the AP No.2 disengagement was recorded on a word slot in the subframe (1948:26) of the DFDR. According to information provided by a manufacturer, the AP discrete (ON/OFF) data may delay up to one second on the data bus from the sensor to the time when the data is recorded on the DFDR. Therefore, an actual time of the AP disconnection may have been earlier than 1948:26.

At 1948:26, the aircraft abruptly pitched up to +7.4° with the vertical G reached a value of + 2.8 G at the top of the first oscillation. Subsequently, at 1948:28, the vertical G reached a value of –0.5 G and the pitch angle was 0° at the bottom of the first oscillation.

At 1948:25, the CAS reached 368 knots, and thereafter began to decrease.

The aircraft completed five pitch oscillations (including the first abrupt pitch-up) over 15 seconds between 1948:26 and 1948:41, during which the vertical G and the pitch angle varied between +2.8G and –0.5G and between 0° and 9.1° , respectively. It is estimated, based on the values of the CWS PITCH and CCP on the ADAS during this time frame, that forces were repeatedly exerted on the Captain side's control column in the ANU and aircraft nose-down (AND) directions.

The speed brakes moved to their retracted positions between 1948:38 and 1948:39.

At 1948:41, data indicating the engagements of the AP No.1 and the A/T were recorded on the DFDR, around which the pitch oscillations began to dampen out.

The TRAs (Throttle Resolver Angle) advanced to around 54° at 1948:27 and maintained the angles until all of the three throttles moved back to their idle stop positions at 1948:43. It is estimated that the throttles were advanced at a rate of 32 degrees per second after the AP No.2 disconnected. According to McDonnell Douglas, the autothrottles are capable of commanding a throttle movement of up to 8 degrees per second. Therefore, it is estimated that the throttle advance was independent of the automatic system.

Additionally, slight AND changes in stabilizer deflection were recorded on the DFDR from 1948:26 until 1948:41 when the AP No.1 engagement was recorded. These stabilizer deflections are estimated as follows;

- were independent of the AP, since it was off.
- Were not a function of the attitude hold logic of LSAS, because more than 2 pounds of force were being applied to the control column.
- were not a function of the speed protection function of LSAS, since the stabilizer deflection was in the AND direction.

Among these stabilizer deflections, there was a speed of the stabilizer deflection corresponding to the manual trim speed.

3.3 Analysis of Abrupt Pitch-up followed by Pitch oscillations

It was estimated that contributing scenarios to the occurrence of the abrupt pitch-up followed by the pitch oscillations were as follows.

(1) Abrupt increase in the airspeed during the aircraft's high-speed descent
(2) The AP override followed by the AP disconnection
(3) Abrupt pitch-up following the AP disconnection

(4) Pitch oscillations due to continuous forces exerted on the control column and the aircraft's longitudinal stability characteristics

3.3.1 Abrupt Increase in the Airspeed during the Aircraft's High-speed Descent

(1) Variations in the wind that acted on the aircraft

While the aircraft was descending with its airspeed of 350 knots, the CAS once decreased to approximately 344 knots between 1948:06 and 1948:07, and thereafter abruptly increased followed by exceeding the V_{MO}; the V_{MO} is "an operational limitation" or "a speed that pilots may not deliberately exceed.

The abrupt increase in the airspeed is analyzed as follows:

As is understood from Appendix 3-1, it is estimated that the aircraft encountered significant wind changes around the time when the CAS abruptly increased, in which the tailwind once increased and then rapidly decreased. This is consistent that the aircraft had been flying with a headwind abruptly changing from the tailwind. The rate of changes in the wind speeds reached approximately 1.7～2.8 knots/sec. It is estimated that the significant changes in the wind speeds resulted in abrupt increase in the CAS.

An estimation of vertical wind activity was not made because the Angle of Attack (AOA) data recorded on the ADAS were suspected. However, it is estimated, based on the result of analysis of changes in the pitch angle shown in Appendix 2, that the vertical wind contribution to the accident was almost negligible.

(2) MD-11 Autopilot's Speed Limiting Logic

The MD-11's autopilot speed limiting logic imposes limitation on the load factor what is called as "G-limit" such that variations in the load factor during flight are limited within a certain value by calculation in the FCC.

The maneuvering G-limit, which is operated within a delta of 0.07G when the AP is engaged in the FLC mode, increases to 0.2G when the filtered airspeed used in the FCC reaches V_{MO}-3 knots.

An ANU force began to be exerted on the Captain's side control column between 1948:15 and 1948:16, but the RIB elevator driven by the AP No.2 began to move in the AND direction (contrary to the Captain's control).

It is estimated that the RIB elevator's movement in the AND direction was due to the AP No.2 attempting to arrest the increase in the pitch angle in order to operate the airspeed within the maneuvering G-limit of 0.07G.

As a result of this, values of the vertical acceleration (G) had been kept within less than 1.1G until a time at the midpoint of the subframe (1948:24).

It is estimated that a major contributing factor to what the vertical G began to increase at the midpoint of the subframe (1948:24) was the effect of the increase in the pitch angle caused by an excessive backpressure on the control column, and resultantly the maneuvering G-limit did not increase to 0.2G.

What the maneuvering G-limit did not increase is explained as follows;

As mentioned in 2.11.1(2)①, the airspeed used by the AP (FCC airspeed) lags behind the indicated airspeed because the FCC airspeed is filtered in the FCC. The time lag becomes a factor in airspeed filter convergence when the wind rates exceed 1.1 knots per second. Thus, it is estimated that the FCC airspeed had not reached V_{MO}-3 knots (at which the maneuvering G-limit increases to 0.2G).

It is estimated that the FCC's airspeed filter lag began to critically affect the AP's ability to control the airspeed when the aircraft encountered severe wind changes with sustained windshear rates of 1.7～2.8 knots/sec which occurred in this accident.

The above scenarios are shown in Appendix 3-2 as a diagrammatic chart.

(3) The pilot's actions to arrest the increasing airspeed

As already mentioned above, an ANU force began to be exerted on the Captain side's control column between 1948:15 and 1948:16. this is estimated to have resulted from the Captain exerting backpressure on the control column in an attempt to arrest the increasing airspeed. Additionally, the speed brakes (Spoilers) began to deploy at 1948:21 and then extended to their full deflections at around 1948:25. However, the CAS exceeded the V_{MO} at 1948:24 and reached 368 knots at 1948:25. These scenarios are explained as follows;

The AP No.2 was still engaged when the Captain began to exert backpressure on the control column.

Even though the pilot exerts backpressure on the control column with the AP engaged in an attempt to make the aircraft pitch nose up, the AP will command nose-down elevator to operate within the maneuvering G-limit (0.07G) as described in item (2) above. Therefore, it is estimated that the aforementioned Captain's actions did not fully arrest the increasing airspeed.

Then, if the effectiveness of the speed brakes is discussed, the role of them for decreasing the airspeed is to produce a nose up pitching moment and increase an aerodynamic drag.

When the speed brakes were deployed with the autopilot engaged in the FLC mode, the response of the aircraft system is considered as follows.

In the FLC mode with the autopilot engaged, airspeed is controlled by aircraft pitch attitude changes, referred to as "speed on pitch."

In the case of this accident, during the timeframe of speed brake extension, data indicate that the filtered FCC-airspeed did not keep up with the actual CAS in decreasing tail wind condition which resulted in a speed excursion. (Refer to Appendix 3-2) In such condition, speed brake deployment in the FLC mode will not slow the aircraft speed, rather, deployment results in an increased rate of descent as the autopilot would maintain the target airspeed. That is, in the FLC mode, when the speed brakes are deployed, the autopilot will not attempt to slow the aircraft, but will command a nose down elevator to maintain speed.

In analyzing the elevator position data during speed brake deployment, there are two reasons for the commanded nose down elevator from the logic of the autopilot.

The autopilot inner loop will attempt to counter the normal nose up pitching moment due to the aerodynamic changes in the wing and changes in the downwash on the tail. Secondary, the autopilot outer loop will command a nose down elevator to maintain speed.

In addition to above, in the case of this accident, as mentioned in item (2) above, it is estimated that the maneuvering G-limit with the autopilot engaged remained 0.07G, and so it is estimated that the nose-up pitching moment would be temporary and that the increase in aerodynamic drag would not quickly produce the effect of decreasing the airspeed.

Taking above into consideration, it is estimated that even though the speed brakes were deployed shortly before the airspeed will exceed the V_{MO}, the effectiveness of the speed brakes for arresting the increasing airspeed was not produced.

Meanwhile, according to the Captain's statement, there was a possibility that he moved the pitch thumbwheel (V/S wheel) on the FCP to change the rate of descent in an attempt to arrest the increasing airspeed. If he adequately carried out this action, the AP had to be changed from the FLC mode to the V/S mode. The DFDR recordings, however, did not show any evidence that such mode changes of the AP were carried out. Neither did the postaccident investigation reveal any malfunction in the AP corresponding to the above event.

As another control method to suppress rapid increase of the airspeed, if the pilot switched the control into manual mode by disconnecting the AP, deployed the speed brakes and imposed nose-up input onto the control column properly, it is considered that the expected decrease of the airspeed could be attained.

3.3.2 The AP override followed by the AP disconnection

Although the AP driven inboard elevator will back drive the other three elevators through mechanical linkages while the AP is being overridden by the direct control column inputs in a direction to change the pitch attitude, the three elevators can relatively respond to the control column deflections due to a "mechanical play" of the linkages. On the other hand, the AP driven inboard elevator, which is directly connected to the AP-servo, resists moving to the elevator angle consistent with the control column deflections. A difference between the angle of the AP No.2 driven RIB elevator and other three elevators began to noticeably increase after 1948:16. It is estimated that the difference was caused by the occurrence of the aforementioned conditions as a result of the AP being overridden.

An excessive force on the control column increases a difference between the actual position of the AP driven inboard elevator and the AP commanded position for that elevator, and the FCC ECRM function will disconnect the AP when the difference exceeds a certain limit for a certain period of time.

In the case of this accident, it is estimated, as mentioned in section 3.2.2, that the RIB elevator had been driven by the AP No.2 command in the AND direction together with the pilot's override control column inputs in the ANU direction in an attempt to arrest the increasing airspeed until the time shortly before the aircraft abruptly pitched up. It is estimated that the AP No.2 was disconnected by the FCC ECRM function as a result of the AP being continuously overridden.

Refer to Appendix 15 concerning a supplemental explanation of the AP disengagement.

3.3.3 Abrupt Pitch-up following the AP Disconnection

A considerable force will be required for a pilot to override the AP by the direct control column input because of the AP resistance.

When the AP is disconnected while a significant force is being applied to the control column, the AP driven elevator abruptly moves to match the position of the other three elevators and all four elevators are further deflected by a force exerted on the control column. This produces an abrupt pitch upset accompanied by a large amplitude of vertical acceleration.

At the time of the accident, because the AP was disconnected while the pilot exerted an ANU force on the control column, it is estimated that the abrupt pitch-up was caused by a combination of the simultaneous movement of all of the four elevators in the ANU direction at the time of the AP disconnection and the nose-up pitching moment produced by the speed brakes which had been counteracted by the AP driven RIB elevator until the AP No.2 was disconnected.

3.3.4 Pitch Oscillations due to Continuous Forces exerted on the Control Column and the Aircraft's Longitudinal Stability Characteristics

The aircraft repeated five large amplitude pitch oscillations including the first abrupt pitch-up for approximately 15 seconds between 1948:26 and 1948:41.

As detailed in Appendix 2, it is estimated that the pitch oscillations were attributed to the interactions between the MD-11 longitudinal stability characteristics and the pilot's ANU and AND control inputs.

Further, from the graphical data attached in Appendix 2, it can be understood that the pitch oscillations showed tendency to dampen out corresponding to a decrease in values of the CCP after the pitch oscillations completed

It is likely that a precipitation into a so-called PIO (Pilot Induced Oscillations) was one of the possible factors to cause the pitch oscillations.

It is understood that the PIO is an inadvertent, sustained series of an aircraft oscillation resulting from pilot's control inputs in an attempt to recover from an aircraft upset.

It is also understood, on the precondition that stability inherent in an aircraft is not compromised, that when a PIO occurs, it usually ends when the pilot realizes that his inputs are part of the problem and he then releases the control.

The AAIC recognizes that, in the case of accidents similar to this accident, there were some aircraft accident investigation reports in which the pitch oscillation events were described by using a term of "Pilot Induced Oscillations" or "Overcontrol-Related PIOs".

However, aircraft designers view that PIO problems should be fixed in the design phase. Thus, in recent years, a term Aircraft-Pilot Coupling (APC) has been used in explaining events similar to the PIO. The APC offers a broader notion including not only aircraft oscillations but also other extreme and unwanted motion of the aircraft.

No matter which term is used, it is estimated that, in the case of this accident, the pitch oscillations occurred resulting from the continuous interactions between the pilot's control column inputs in the ANU and AND directions and the MD-11 longitudinal stability characteristics.

At present, in the case of MD-11, it is considered effective for the pilot to relax pressure on the control column or release the control column if necessary when encountering pitch oscillations like those at the time of the accident so that he can recover from the pitch oscillations, because longitudinal stability inherent in the MD-11 in manual control is augmented by systems including the LSAS.

The following are the further details of the pitch oscillations.

It is commonly said that there is a delay of about 0.2 seconds before a pilot begins to take corrective action (initially nose-down control input) in the event of an abrupt pitch-up.

The manufacturer states that there is an another delay of 0.2 seconds prior to the beginning of the elevators' nose-down deflection responding to the pilot's nose-down control input.

In addition, it is estimated that there is a delay of 1.5 seconds until the pitch angle begins to decrease after the elevators' nose-down deflection began.

Thus, about 1.9 seconds will elapse from the time when the pilot recognizes the need for making the aircraft pitch-down until the pitch angle begins to decrease. This elapsed time will account for approximately 60% of a cycle of about three seconds with which the pitch oscillations occurred at the time of the accident.

When the time equivalent to about 0.6 cycle stated above elapsed, the phase of the pitch oscillations would have gone forward so that there is a possibility that the aircraft's attitude already advances halfway through the pitch down phase when the pilot's nose-down input in response to the aircraft's nose-up movement takes effect. Thus, the nose-down pitching moment produced after a 0.6 cycle delay of the pilot's AND control input turns out to be added to the aircraft's nose-down movement leading to develop the aircraft's further nose-down movement.

Similarly, the pilot's ANU control input in an attempt to stop the aircraft's nose-down movement produces the nose-up pitching moment after a 0.6 cycle delay, which is likely to result in developing the aircraft's further nose-up movement contrary to the pilot's intention.

As understood from the above, when the pilot continues to exert forces on the control column in the ANU and AND directions in an attempt to stabilize the aircraft attitude, the aircraft is likely to generate pitch oscillations contrary to the pilot's actions.

Even if the pilot tries to make quicker and adequate control inputs to stabilize the aircraft attitude, it is considered that a human's reaction speed and ability to momentarily and properly perceive an adequate force which should be exerted on the control column has a limitation.

Therefore, in the case of MD-11, it is considered important for a pilot to relax pressure on the control column or release it if necessary when precipitating into abrupt pitch upsets like those at the time of the accident so that he or she can stabilize the aircraft attitude by the longitudinal stability inherent in the LSAS when flying manually.

3.4 Factors related to the Pilot Control

At the time of the accident, the pitch oscillations resulted from considerable forces exerted on the control column after the aircraft abruptly pitched up following the AP disconnection.

It is considered to be likely that contributing to such pilot's control inputs was the pilot's insufficient familiarization with characteristics of the AP and the longitudinal stability inherent in the MD-11 and procedures regarding recovery from pitch oscillations, and it is considered that the following factors would have contributed to the aforementioned pilot's controls;

(1) Insufficient descriptions in FCOM (and JAL's AOM), etc.

Pertaining to what is essential, that the pilot should not override the AP and relaxes pressure on the control column or releases the control column after the abrupt pitch-up and to procedures the pilot should take when the aircraft flying with the AP engaged approaches or will exceed the V_{MO}, there was a lack of sufficient descriptions regarding the following items in the previous McDonnell Douglas's FCOM and JAL's AOM before the accident

① About the AP override

As mentioned in section 2.11.1 (2), in relation to the MD-11's AP, McDonnell Douglas presented a NOTE "Never Override the Autopilot" at the seminar to operators which was held before the accident occurred.

Concerning the expression ("Never Override the Autopilot") which is equal to an "Operational Limitation" prescribed in Japan's Civil Aeronautics Law, the previous FCOM described only the CAUTION note "Do not attempt to overpower the autopilot with control force" in section related to "Severe Turbulence" before the occurrence of the accident.

Corresponding to the above NOTE, the previous JAL's AOM put an expression "Do not attempt to override the autopilot with control force".

In addition, although the previous FCOM and JAL's AOM referred to the pilot over control such as "overriding the AP with control forces can cause the AP to disengage with too much control input, which could result in over control", those did not refer, with more specific descriptions, to an abrupt pitch-up resulting from overriding the AP.

It is considered that it would have been beneficial to the pilot if the AP system had a logic to annunciate and/or flash an alarm in the cockpit when the AP was overridden. Such logic, however, was not specifically incorporated into the MD-11's AP system.

② MD-11 High Altitude Manual Control Characteristics

Regarding the MD-11's manual control characteristics at high altitude, the previous FCOM (the JAL's AOM) referred to the note "Longitudinal control forces at high altitude will be lighter than those which the pilot experiences at low altitude, which could result in over control" and the note "When the autopilot is off, use minimum control inputs to fly attitude and allow the LSAS to maintain attitude by reducing pressure on the control column whenever possible" in the section related to flight in "Severe Turbulence". Such descriptions, however, were not contained in sections other than the section related to a flight in "Severe Turbulence".

In addition, regarding recovery procedures after the AP disconnection, the previous FCOM (JAL AOM) did not touch on the term "Release the control column if necessary".

③ Procedures taken by pilots when the airspeed is imminent to exceed the V_{MO}

The CAS abruptly increased and exceeded the V_{MO} before the accident occurred.

The V_{MO} is defined as "an operational limitation" or "a speed that pilots may not deliberately exceed.

It was revealed from the result of the investigation that the airspeed could exceed the V_{MO} depending upon a target airspeed selected on the FCP because the FCC-airspeed lags behind the airspeed in converging on the selected target airspeed depending upon the rate of changes in the wind speeds.

From the aircraft designer's viewpoint, the V_{MO} is defined as "a speed that momentarily exceeding V_{MO} does not adversely affect the safety of flight". It is, however, considered that pilots will attempt to arrest the increasing airspeed in some actions when the airspeed approaches or will exceed the V_{MO}. In this case, it is considered desirable that the more the aircraft depends on computer autoflight system, the more the procedures to arrest the increasing airspeed taken by the pilot should be clarified.

However, the JAL AOM did not describe the possibility that the airspeed could exceed the V_{MO} (an operational limitation) during descent with a target airspeed selected on the FCP and how pilots should cope with the airspeed about to exceed the V_{MO}.

(2) A Lack of Education and Training on MD-11 by using Simulator

Because the pilot of the said aircraft was given a "MD-11 Pilot Flight Training Guide" organized by the JAL operator in relation to the MD-11 longitudinal stability at high altitude, it is estimated that he had an oppotunity to know the reason why the AP should not be overridden with excessive force on the control column resulting in G excursions sustained by the aircraft at the time of the AP disconnection, even though such description was provided in a section " When encountering severe turbulence" of the training guide.

Subsequently, the pilot also received simulator training on the MD-11's high altitude handling characteristics.

The investigation, however, revealed that simulator training assumed that the AP is disconnected by the pilot's override resulting in the aircraft's abrupt upsets, which the pilot experienced at the time of the accident, was categorized as a prohibitive item, such training was not basically included in the simulator training syllabus before the accident. In addition, it is estimated that the MD-11 flight simulators were unable to reproduce pitch oscillations with a single cycle. Therefore, it is considered to be likely that the pilot did not have a chance to sufficiently familiarize himself that a pilot should not exert an excessive force on the control column during flight with the AP engaged, the MD-11 longitudinal stability characteristics, and procedures in recovering from the pitch oscillations.

Further, it is estimated as a result of the investigation that the MD-11 flight simulators before the accident were not able to reproduce the airspeed's changes in excess of the V_{MO} affected by significant changes in windspeed like those encountered in this accident. Thus, it is considered to be likely that the pilot did not have a chance to sufficiently familiarize himself with procedures taken by pilots when the airspeed is approaching or will exceed the V_{MO} during flight with a target airspeed selected on the AP.

3.5 Vertical G Load sustained by the Cockpit and the Aft Galley

By using the DFDR data, vertical G load sustained by the cockpit and the aft galley where the serious injuries were concentrated was estimated.

From the result of the estimation as shown in Appendix 4, maximum value of the vertical G load occurred at the top of the first violent pitch-up; the value was +2.5G at the cockpit and reached +3.2G at the aft galley. The peak value of the negative G was approximately −0.8G.

About the result of the estimation of the pitch oscillations following the first violent pitch-up, the highlight was that three peak values (+1.6～+1.7G) of positive G load without negative G load occurred at the cockpit but three peak values of +2.5G and four peak values of negative G load were sustained at the aft galley.

A small lateral acceleration (G) having a peak-to-peak amplitude of 0.08G was recorded on the DFDR during the time frame of the occurrence of the large amplitude of vertical Gs.

3.6 The Time when Seat belt Sign was on

It is difficult to identify the time when the seat belt sign was switched on because voices and sounds near the time of the accident were not recorded on the CVR. However, putting the statements of the Captain, cabin attendants and passengers together, it is estimated that the seat belt sign was turned on two to three minutes before the aircraft abruptly pitched up.

3.7 Analysis of Injuries

Injuries were classified into serious and minor; the seriously injured persons sustained mainly bone fractures and the slightly injured persons received bruise, wound and sprain, etc.

Regarding the time when the injuries were received, it is estimated based on the statement of the seriously injured persons that they, while walking in the aisle and working in the aft galley, were seriously injured by dropping heavily to the floor and armrests and striking the ceiling and the emergency exit light covers during the violent pitch oscillations.

The serious injuries were concentrated in the rear cabin. This is estimated to have been due to the large amplitude of vertical G load in the rear cabin resulted from the pitch oscillations.

Based on the fact that the seriously injured persons were those who did not fasten their seat belts, it is estimated that they could have been prevented from receiving the serious injuries if they had fastened their seat belts.

3.8 The Reasons that the Injured Persons did not fasten Seat Belts

The reasons that the injured passengers did not fasten their seat belts are estimated as follows from putting their statements together;

(1) in the aisle on the way back to his seat from a washroom

(2) taking a rest in his seat

(3) adjusting her dress in the lavatory

Concerning the injured cabin attendants, it is estimated that after checking whether passengers fastened their seat belts or not because the seat belt sign came on, they were organizing the sale's receipts of duty-free goods and so on because the aircraft was about to land at Nagoya Airport.

3.9 Rescue Activities

There were time constraints in communicating information adequately between the pilots and cabin attendants and performing company radio communications about the situations in the cabin between the aircraft and the JAL Nagoya Airport branch office because the aircraft was in critical phase for approaching Nagaya Airport and as a result, it is estimated that activities in the cabin and on the ground were performed within the scope of the limited information.

Additionally, it is estimated to have taken about 40 minutes from the time when the first ambulance arrived after the aircraft had landed until transferring the injured persons was began because this had to be done carefully.

Further, it would be considered helpful if description is clearly provided in JAL's company manual(s) regarding information exchange between related crew and staff when people on board have been injured in the flight phase where information exchange is restricted as well as concrete procedures in detail in relation to rescue activities in Nagoya Airport, but there was not such description in said company manual(s).

4 CAUSES

It is estimated that this accident was caused as a result that passengers and cabin attendants sustained injuries due to the occurrence of the aircraft's pitch oscillations immediately following the abrupt pitch-up after the seat belt sign had been switched on while the aircraft was descending for land.

It is estimated that, with the exception of one person who received minor injury, the injured did not fasten their seat belts, which contributed to sustaining injuries.

It is estimated that the following sequences induced the aircraft's abrupt pitch-up followed by pitch oscillations;

(1) The airspeed first decreased and then abruptly increased exceeding the selected target airspeed because the aircraft encountered significant changes in the wind speeds.

The airspeed used by the AP (FCC airspeed) lags behind the indicated airspeed because the FCC airspeed is filtered in the FCC. Thus, the AP system (FCC-airspeed) has a time lag in converging the airspeed on the selected target airspeed with wind rates in excess of 1.1 knots per second. Additionally, although the Captain attempted to arrest the increasing airspeed by exerting an aircraft nose-up force on the control column to make the aircraft pitch nose up and so on, the effectiveness of his control column inputs was counteracted by the function of the AP system. As a result of these, the airspeed turned out to exceed the V_{MO}.

(2) The Captain exerted forces on the control column in the aircraft nose-up direction. As a result, the AP was disconnected because the difference between the actual position of the AP driven right inboard (RIB) elevator and the AP commanded position for that elevator exceeded an allowable limit.

(3) The AP disconnection resulted in a release of the AP function that had counteracted the effectiveness of the Captain's control column inputs in the aircraft nose-up direction. This produced the abrupt pitch up.

(4) Because, after the AP disconnection, his control forces were continuously exerted on the control column in the aircraft nose-up and nose-down directions, the aircraft experienced pitch oscillations. Contributing to the continuous pitch oscillations were the interactions between the continuous control column inputs and the MD-11 longitudinal stability characteristics.

Additionally, it is considered to be likely that one of contributing factors to the abrupt pitch-up followed by the pitch oscillations was the pilot's insufficient familiarization with characteristics of the AP system and the longitudinal stability inherent in the MD-11 and procedures in recovering from pitch oscillations, and the following factors contributed to the pilot's insufficient familiarization.

(1) Insufficient descriptions in the FCOM (JAL's AOM) pertaining to the followings;

① About overriding the AP

② About MD-11's handling characteristics in flying manually at high altitude

③ About procedures pilots should take when the airspeed approaches or will exceed the V_{MO}.

(2) A lack of pilot's education and training in the MD-11 simulator.

5 REFERENCES

Concerning measures related to the accident, actions taken by Airlines, Manufacturer and Organizations concerned after the accident are as follows.

5.1 The Aircraft Accident Investigation Commission

After the accident, the AAIC made two "proposals" to the Minister for transport; the Proposals are attached as Appendix 11-1.

5.2 The Japan's Civil Aviation Bureau

Refer to Appendix 11-2 concerning major actions taken by the JCAB after the accident.

5.3 Manufacturer and Airlines

Refer to Appendix 11-3 concerning major actions taken by McDonnell Douglas and the JAL after the accident.

5.4 The National Transportation Safety Board

With respect to this accident and the accident involving another MD-11 operated by American Airlines as flight 107 which occurred in the U.S.A on July 13, 1996, the NTSB issued "Safety Recommendations" with explanations of these two accident to the Federal Aviation Administration.(Refer to Appendix 11-4)

6 SAFETY RECOMMENDATIONS

As a result of the accident investigation, the Aircraft Accident Investigation Commission makes the following recommendations to the Federal Aviation Administration:

Require Boeing Douglas Products Division to review the followings and take appropriate measures:

(1) Further studies on the AP disconnection

The AAIC recognizes that a contributing factor to the abrupt pitch-up in this accident was the AP disconnection resulted from the pilot's overriding the AP with excessive forces exerted on the control column. Therefore, further studies on the followings should be carried out;

① Improvement of the AP system

The AP system should be redesigned so that an AP disconnection resulting from being overridden does not lead to abrupt aircraft upsets.

② Revisions to MD-11 Flight Crew Operating Manual (FCOM)

After the accident, descriptions "The pilot should never apply force to the control column while the autopilot is engaged." and "Applying force to the control column while the autopilot is still engaged has resulted in autopilot disconnects and subsequent abrupt aircraft maneuvers" were included in a WARNING note in the item "GENERAL OVERVIEW" in the "Supplemental Procedures" section of the "AUTOMATIC FLIGHT SYSTEM (AFS)" in Volume Ⅱ of the MD-11 FCOM. Since it is considered that the WARNING note is indispensable for preventing a recurrence of similar accident, it should be moved to a Volume pertaining to Operational Limitations if it is technically difficult for the AP system to be redesigned.

Also, since it is considered indispensable for the pilots to relax pressure on the control column or release the control column if necessary in order to prevent an over control when recovering from the aircraft upsets, these procedures should be described in a Volume pertaining to Emergency/Abnormal Procedures.

③ Studies on incorporating a warning device to alert the pilots that the AP is being overridden

Studies on incorporating a warning device to alert the pilots that the AP is inadvertently being overridden should be carried out if it is technically difficult for the AP system to be redesigned.

(2) Studies on improving the AP characteristics of converging the airspeed on a target airspeed.

The AAIC determines that the airspeed could exceed the V_{MO} depending upon a target airspeed selected on the FCP because the FCC-airspeed lags behind the airspeed in converging on the selected target airspeed depending upon the rate of changes in the windspeed.

Therefore, the following should be carried out with respect to the MD-11 AP system;

① A review of software for the AP system so that the Filtered Airspeed used for speed limiting logic in AP becomes as close as possible to the Indicated Airspeed which pilots can recognize through airspeed indicator, in order to narrow a gap as small as possible between the status of AP airspeed control and the recognition of the pilot concerning actual change of airspeed.

② A review and reinforcement in the FCOM descriptions about the following two items, if it is technically difficult for the AP's speed protection software to be changed.

a. A possibility of the airspeed exceeding the V_{MO} due to the FCC-airspeed's time lag in converging the airspeed on a target airspeed

b. Procedures that the pilots should take when the airspeed is about to exceed the V_{MO}

(3) A review of MD-11 flight simulator's software

A review should be made for the MD-11 simulator training program (including the followings) in order for the pilots to be able to be fully familiar with the MD-11's handling characteristics, if the AP system could not be redesigned as stated in (1)and (2) above.

① Appropriate procedures that the pilot should take when significant changes in wind speed causes the airspeed to abruptly increase and approach or exceed the V_{MO}

② The aircraft's abrupt upsets in the case that the AP is disconnected by being overridden, the appropriate control inputs that the pilot should apply to dampen out the upsets and the pilot's control inputs resulting in continuing the upset

7 OPINIONS

7.1 The AAIC of Japan issued the Proposal on March 5, 1999 in relation to the promotion of the safety belts to be fastened at any time if it is possible.

Meanwhile, it is estimated that those cabin attendants were injured who were continuing their jobs without taking seats even after the sign to fasten seat belt turn on, and so it is deemed appropriate to include in the discussion items of the study corresponding to the Proposal above what cabin attendants to do when the sign to fasten seat belt becomes on.

7.2 In this accident, it is estimated that ages, genders and the status of injuries were not informed to the fire fighting station when the air carrier called the ambulance, because of the reason that those were not yet known to the people on the ground.

Concerning above, as the aircraft was in approach to make landing, it could be said, on the one hand, that information exchange was limited, and on the other hand, however, it is considered that it would be a contributing factor that the system to exchange information between the crew on board the aircraft and the relevant staff on the ground is not fully established when people on board were injured during the flight phase like above.

Therefore, it is deemed necessary for each air carrier to carry out study on the establishment of such system through that necessary information could be exchanged without fail between related crew on board the aircraft and staff on the ground even in the aforementioned situation.

Further, in relation to action to be taken after landing from the flight during which persons on board have been injured, each air carrier should establish procedures corresponding to the characteristics of each airport where the aircraft of each air carrier are in service.

7.3 The Cockpit Voice Recorder (CVR) is a device to record information which is important to carry out analyses objectively concerning what happened in the aircraft before and/or after the occurrence of the accident.

Meanwhile, only the sounds related to the maintenance etc. accomplished after the aircraft had stopped in the spot were recorded in the CVR of the aircraft of the subject.

The CVR of the subject has a capacity to record the sounds of 30 minutes until the CVR stops; on the day of this accident, the time when the aircraft stopped in the spot, i.e. "Block In" Time, was 20:16 JST, and so, if the CVR had been stopped as soon as possible when the engines of the aircraft had been shut down after "Block In", the sounds before and/or after the accident would have been available, which would have been significantly helpful to carry out analyses concerning what had happened in the aircraft before and/or after the accident.

Because of above, it is deemed necessary for relevant air carriers to take appropriate actions through carrying out following studies: technical studies on the modification of the CVR system and studies to facilitate this issue organizationally in order to preclude the CVR record around the accident from being lost carelessly, as well as studies to replace existing CVRs with those which have longer recording time than 30 minutes.

Figure 1 Estimated Flight Route

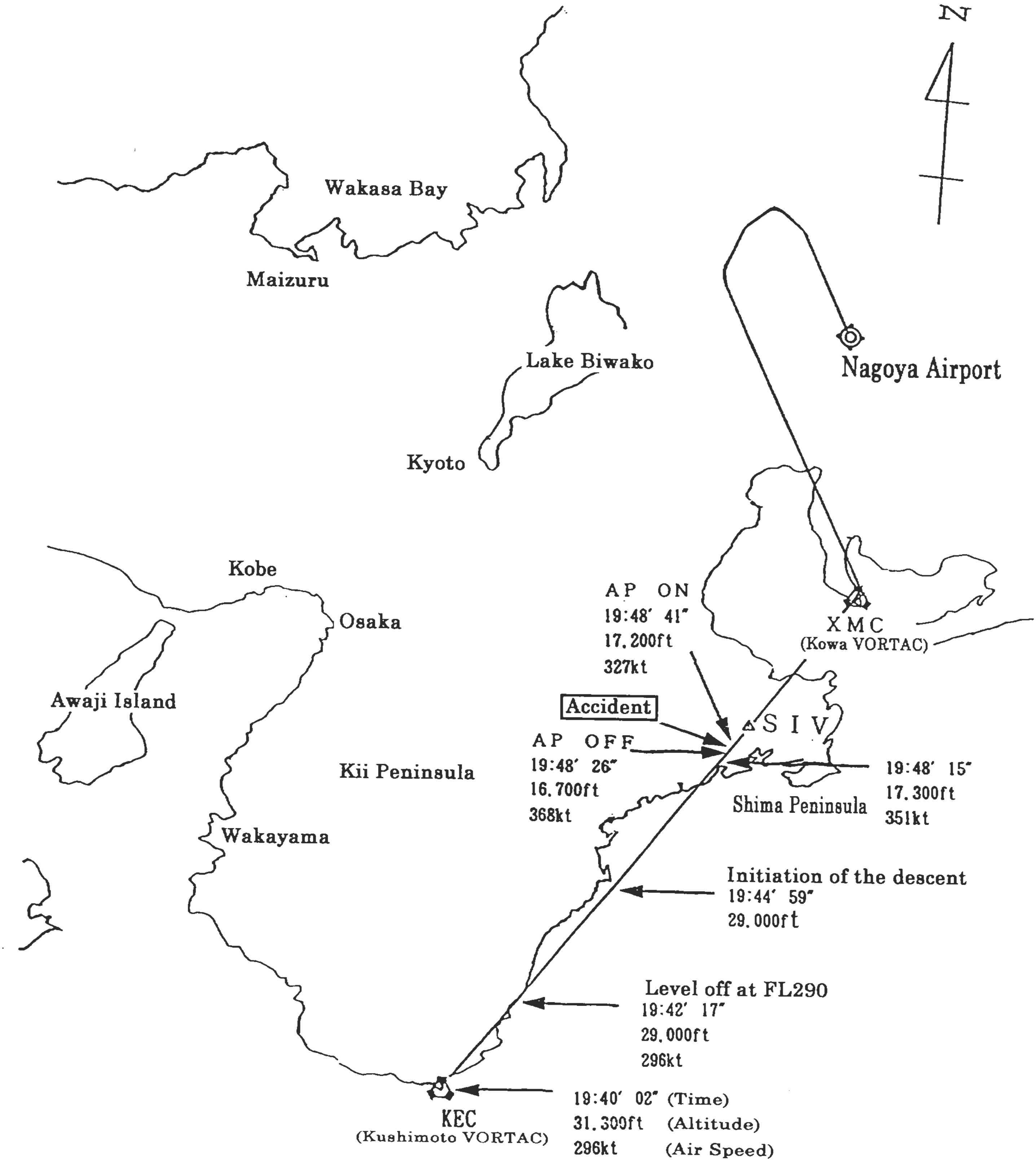


Figure 2 McDonnell Douglas MD-11
Three Views

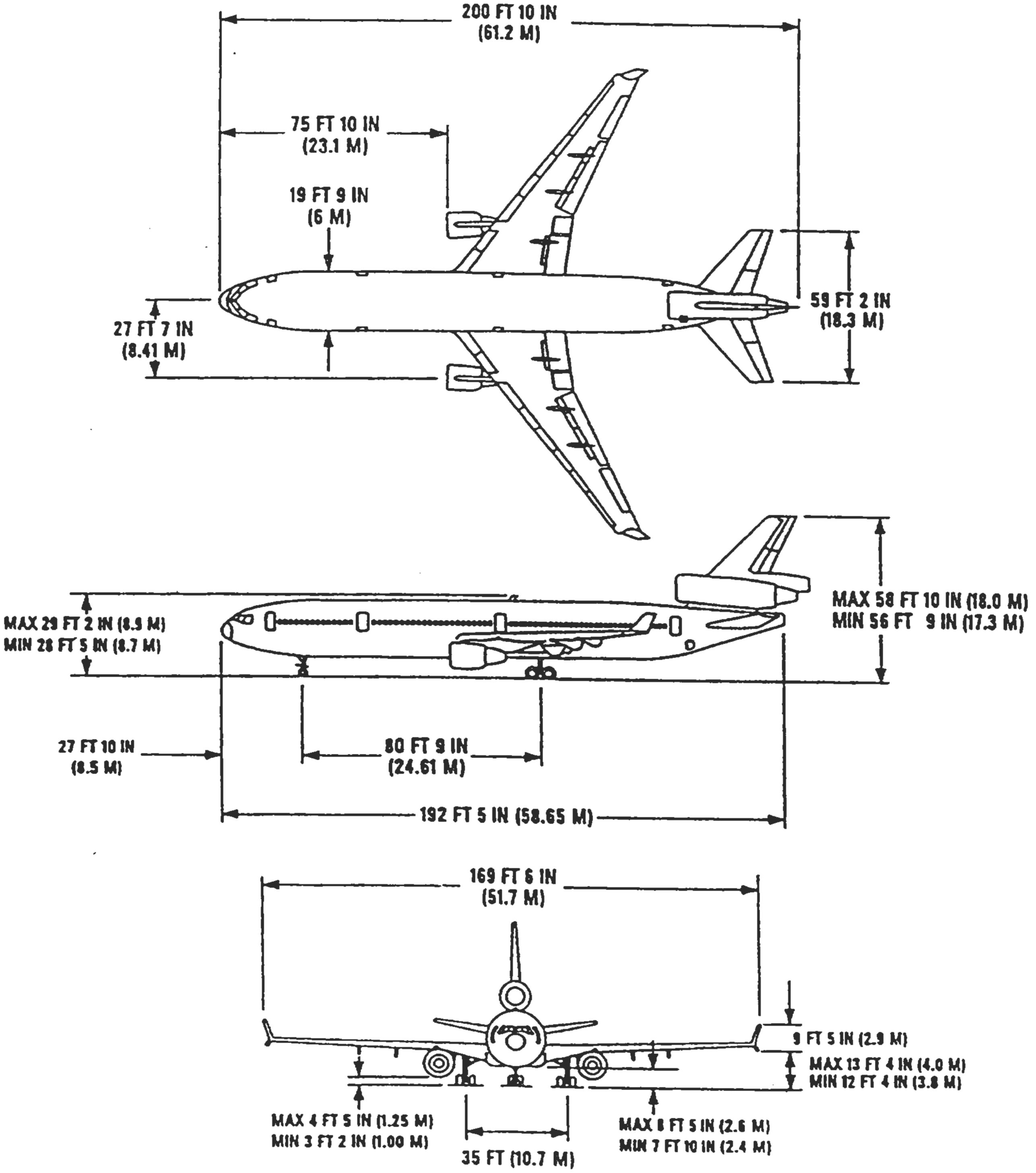


Figure 3 Positions of the Injured Persons in the Cabin at the Time of the Accident

LEGEND

CA: Cabin Attendant
Minor: Minor Injury
Severe: Severe Injury

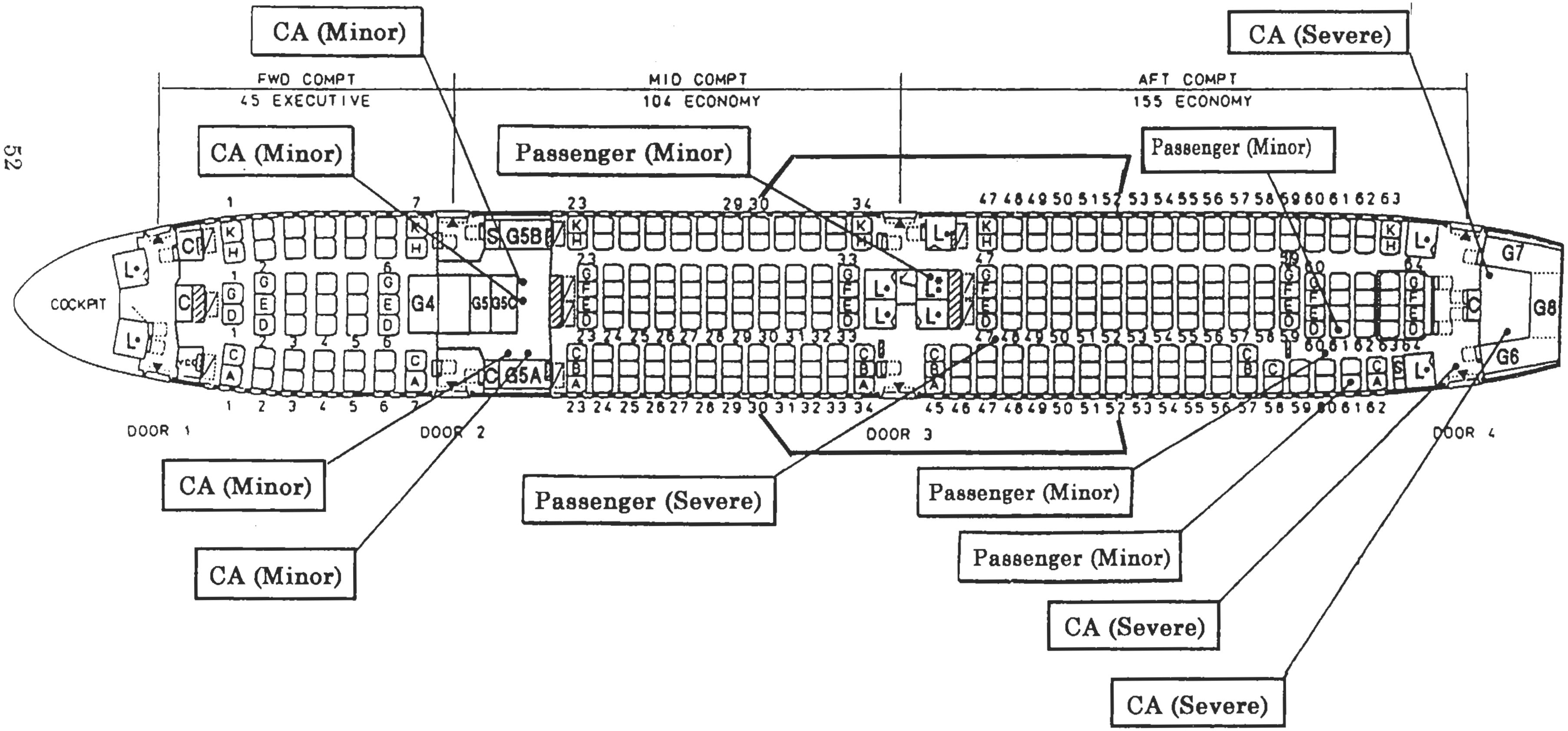


Figure 4 Surface Weather Observation

2100JST on June 8, 1997

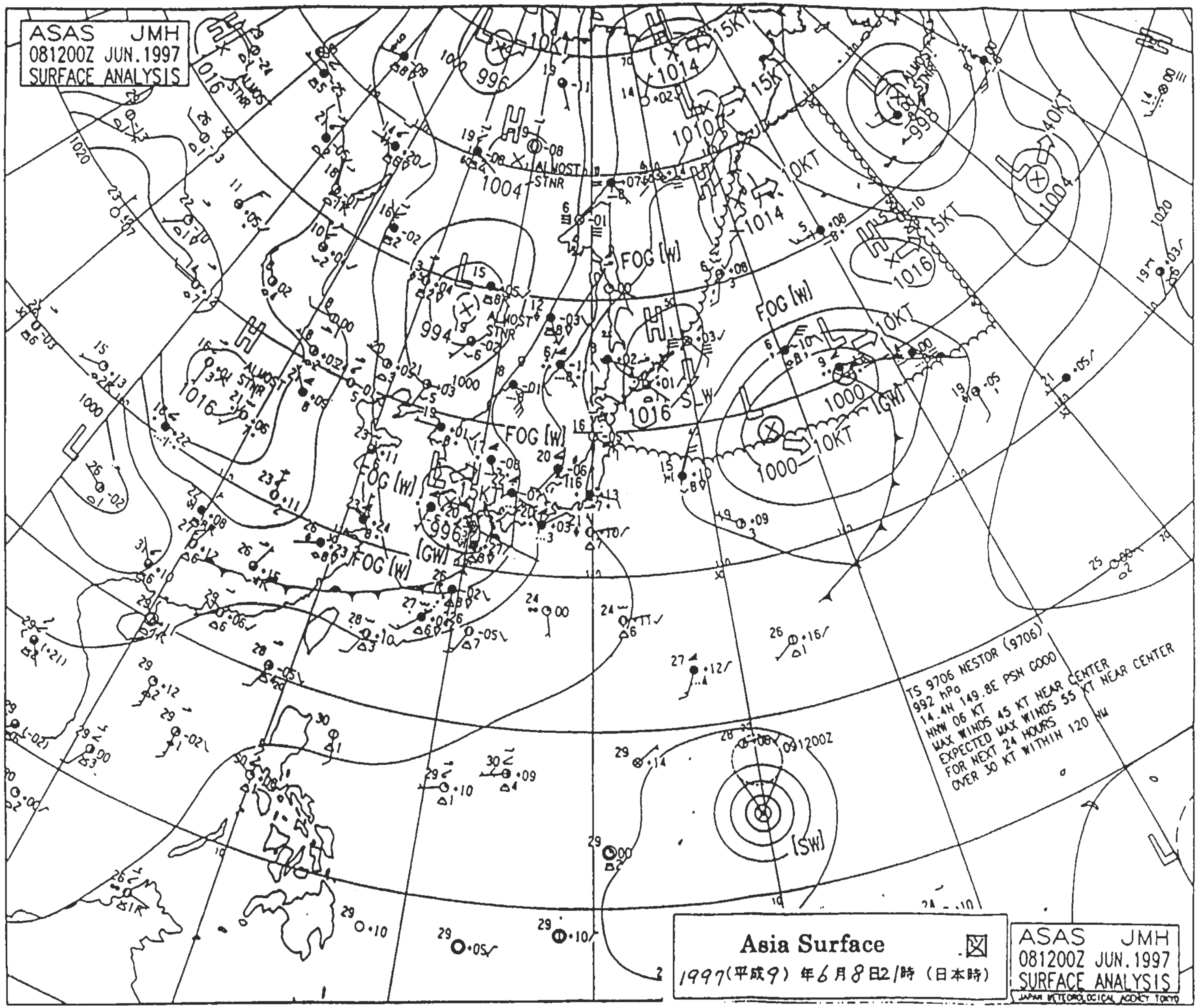
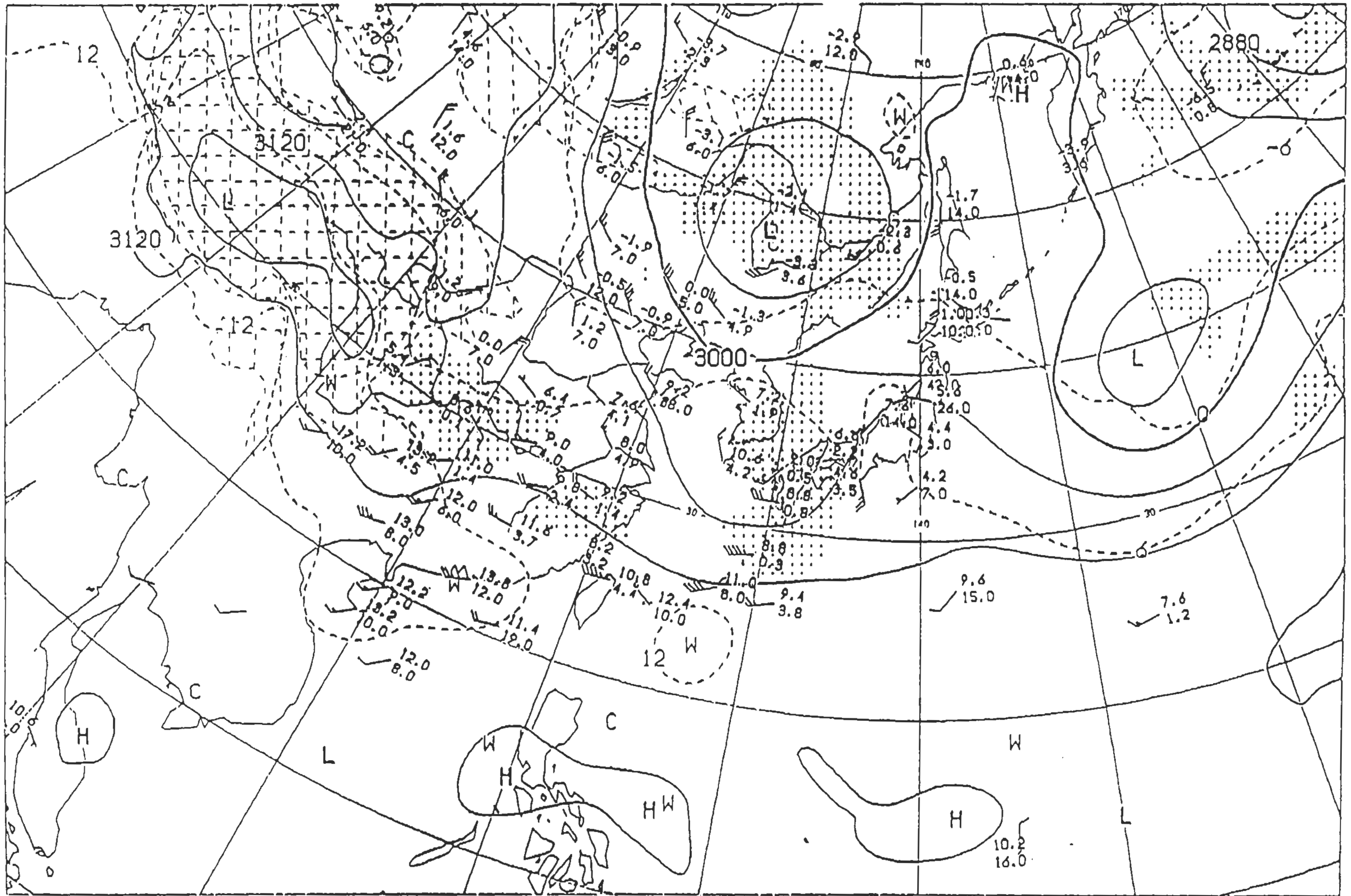
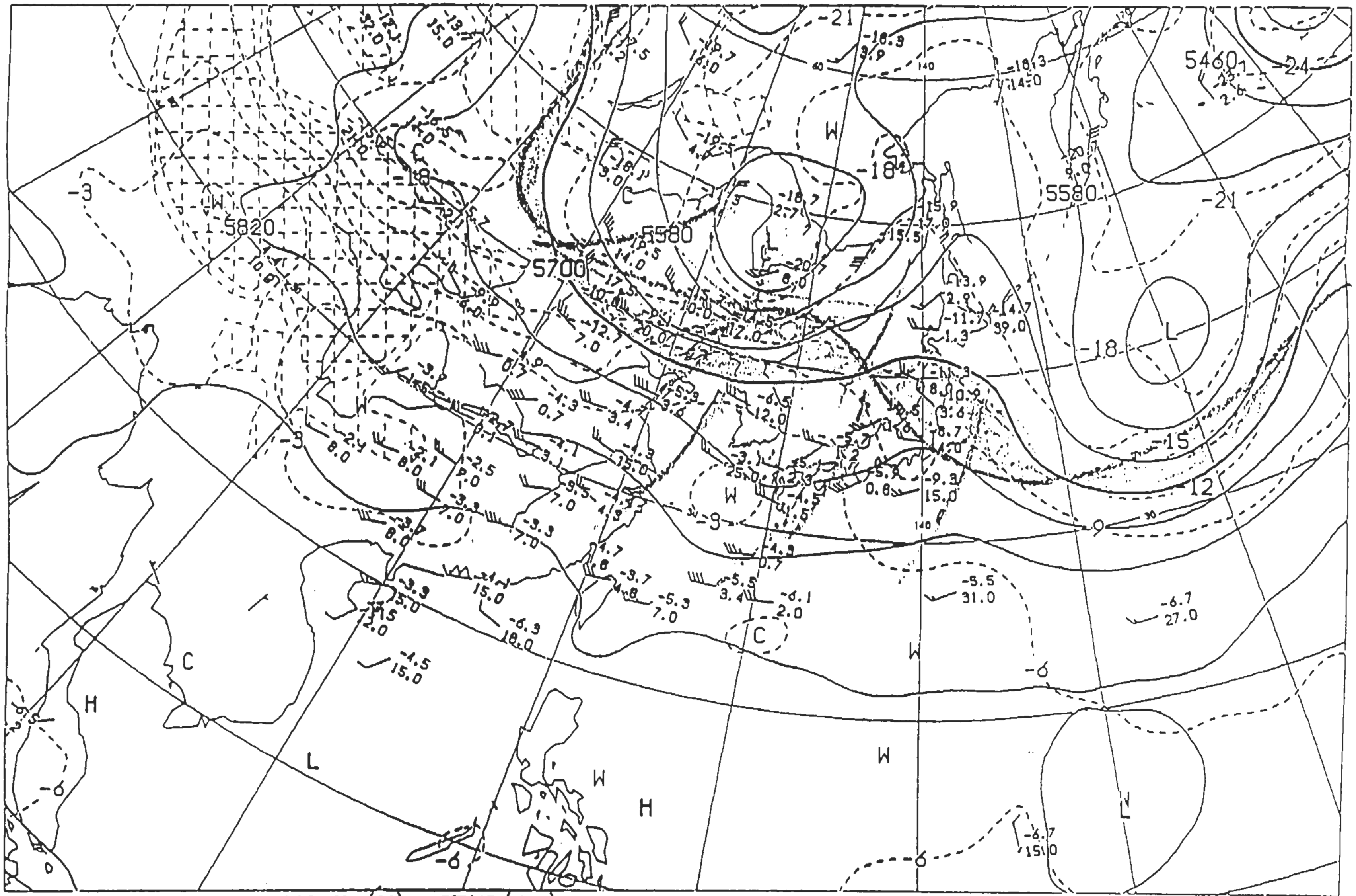


Figure 5 Upper Air Observation (700 hPa)
2100JST on June 8, 1997



ANALYSIS 700hPa: HEIGHT(M), TEMP(°C), WET AREA::(T-TD<3°C)

Figure 6 Upper Air Observation (500 hPa)
2100JST on June 8, 1997



ANALYSIS 500hPa: HEIGHT(M), TEMP(°C)

Figure 7 Nephanalysis Information
2100JST on June 8, 1997

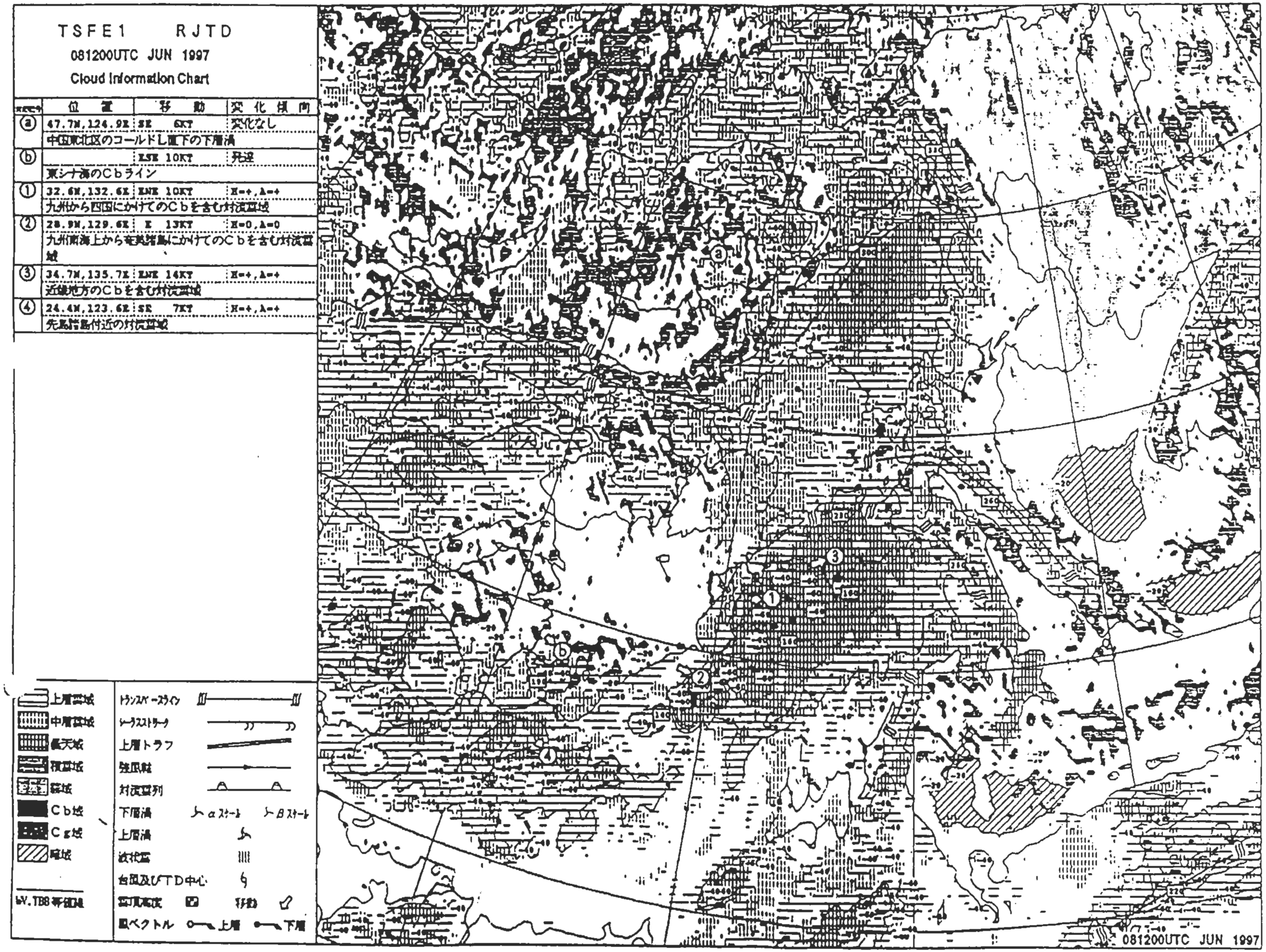


Figure 8 Weather Radar Returns

2100JST on June 8, 1997

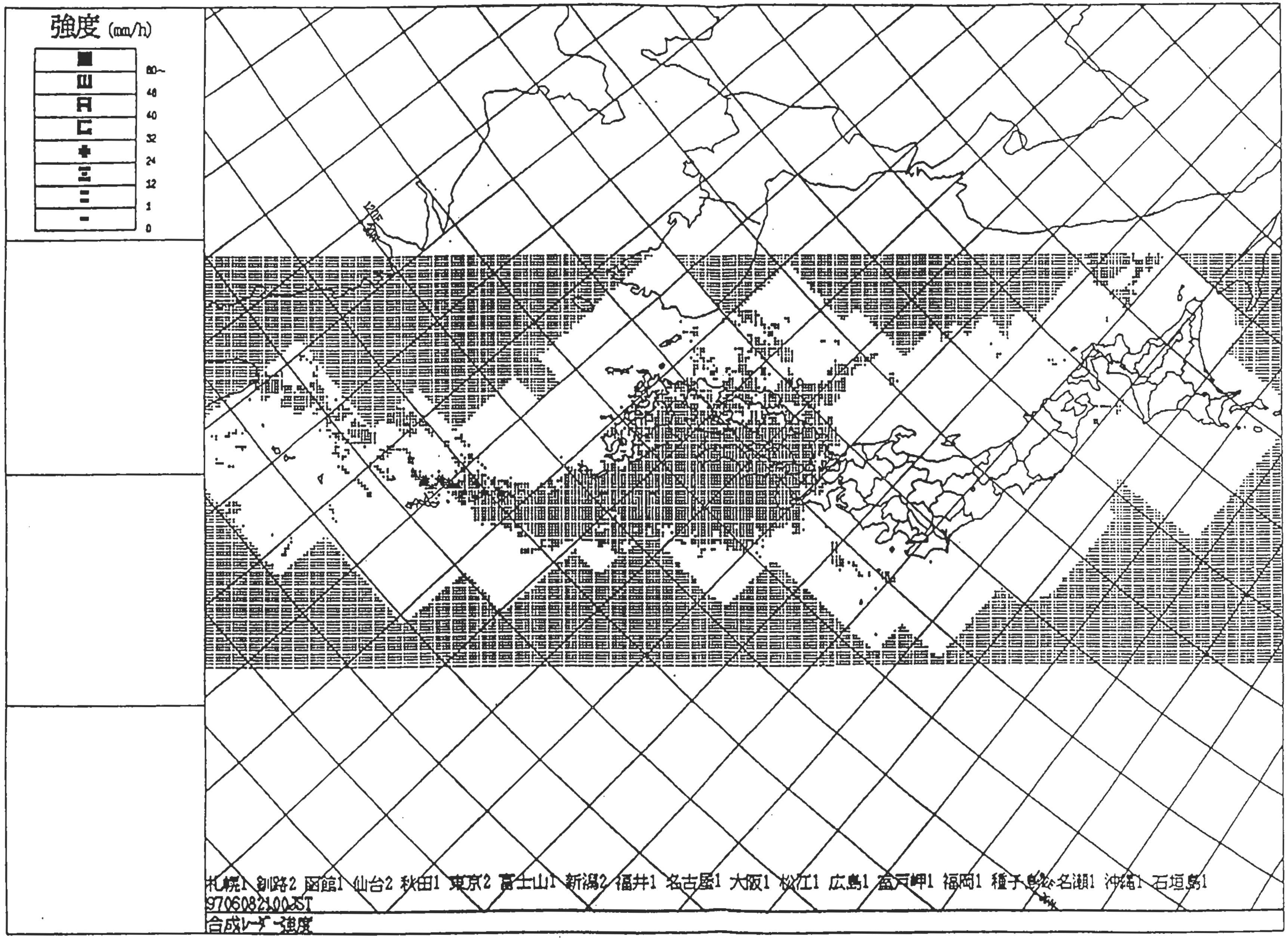


Figure 9　Emagram(Shionomisaki)
2100JST on June8,1997

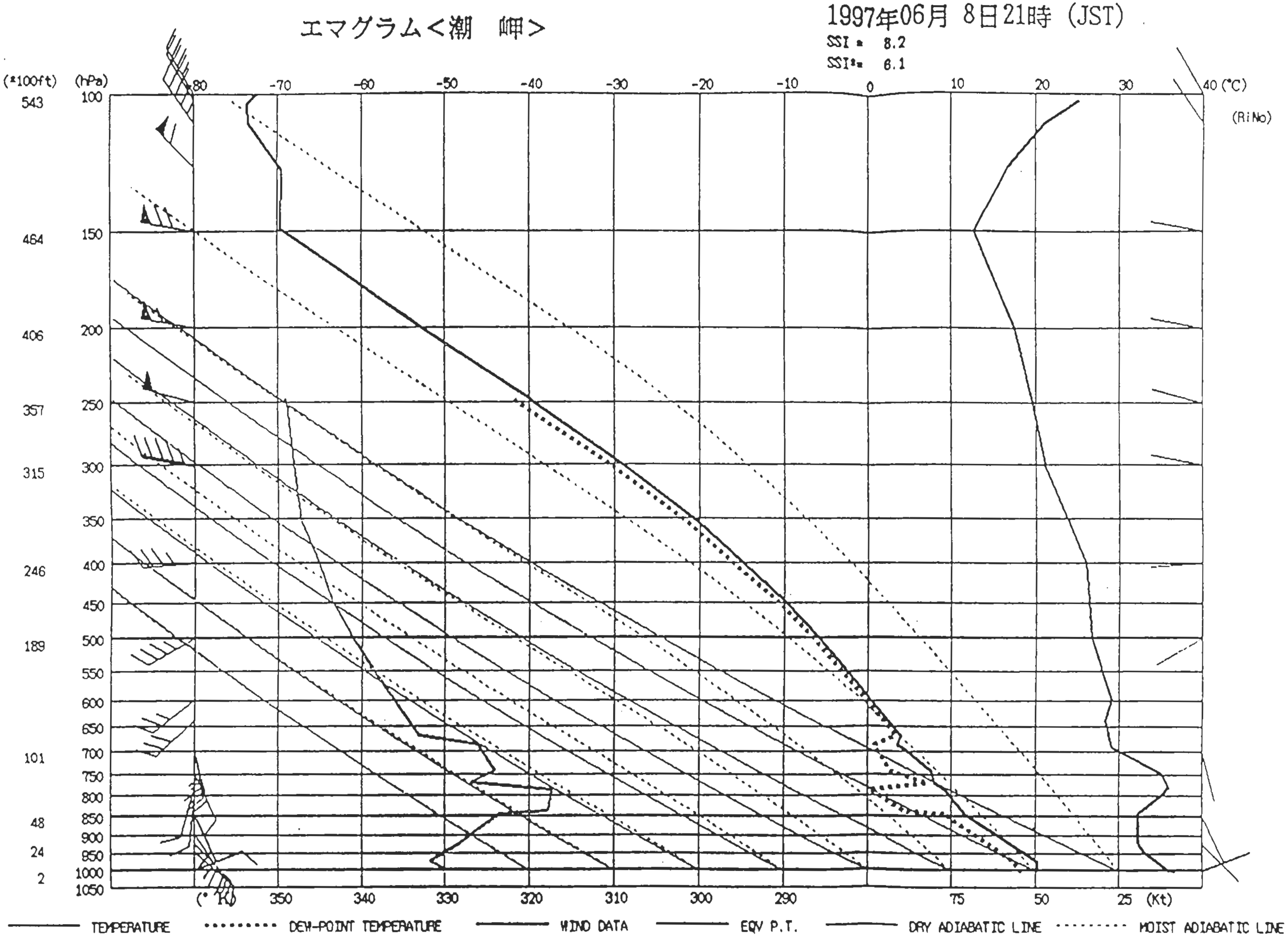
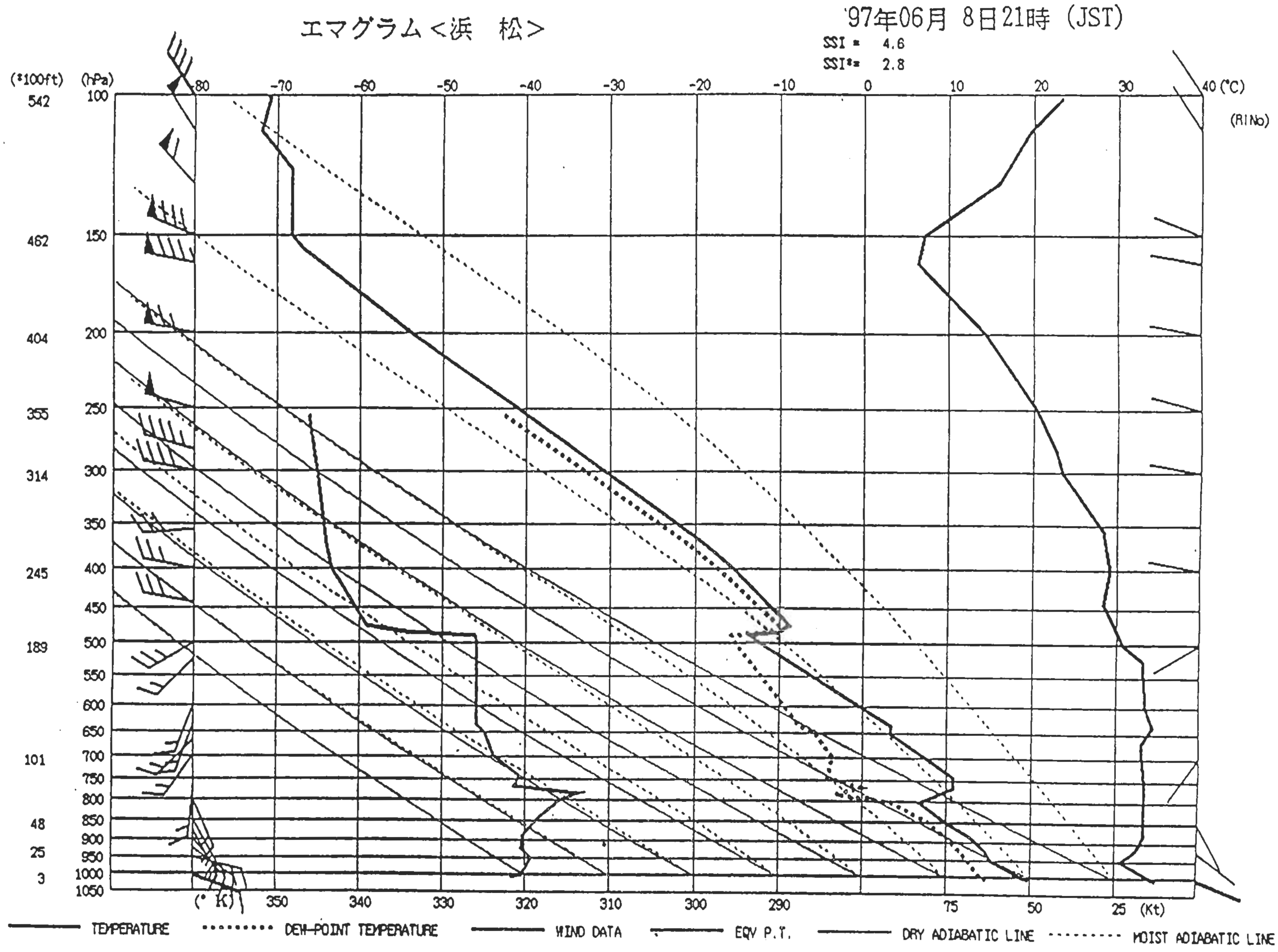
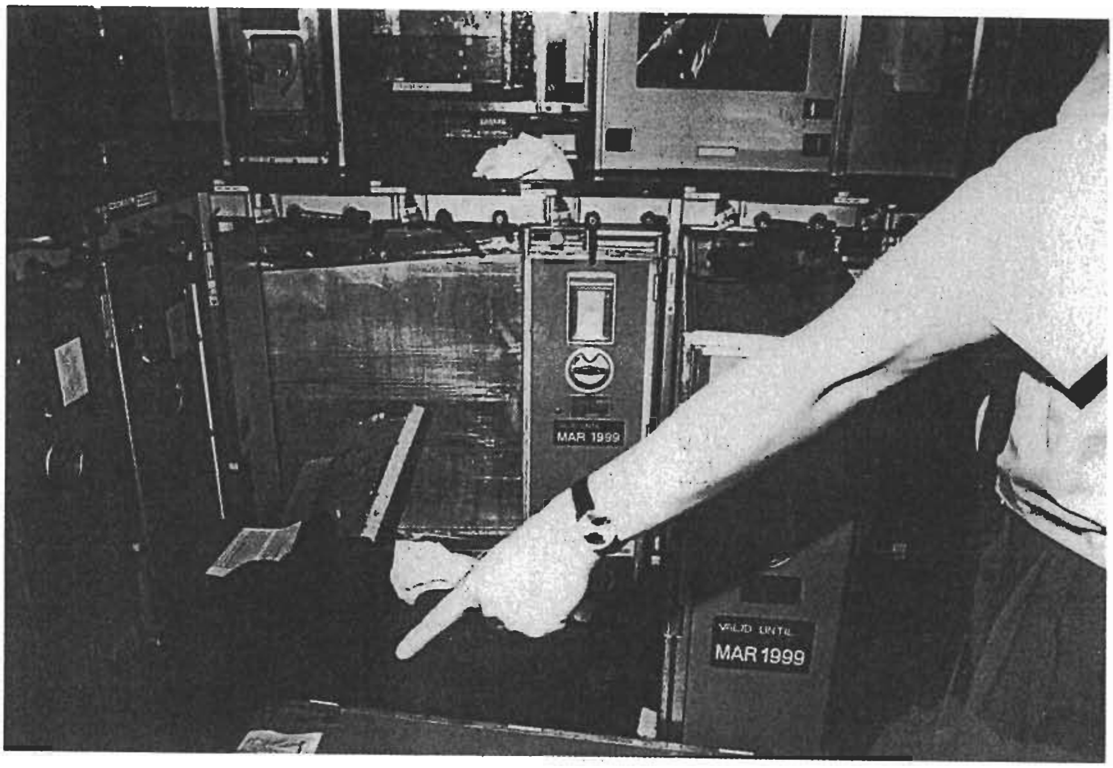


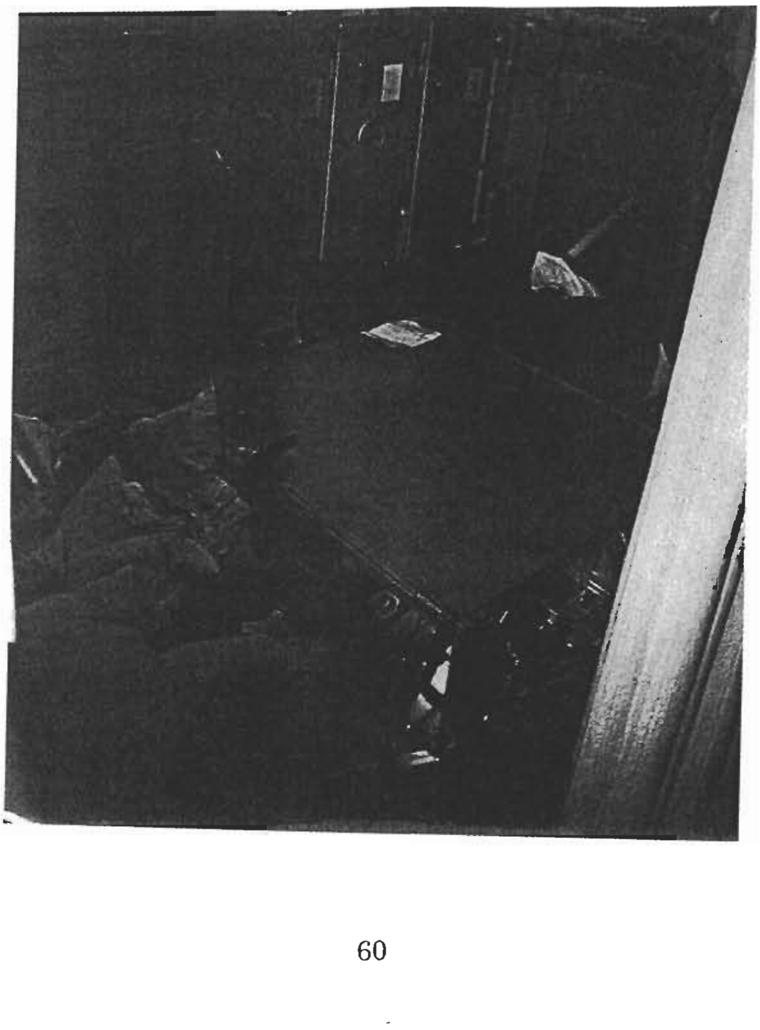
Figure 10　Emagram (Hamamatsu)
2100JST on June 8, 1997



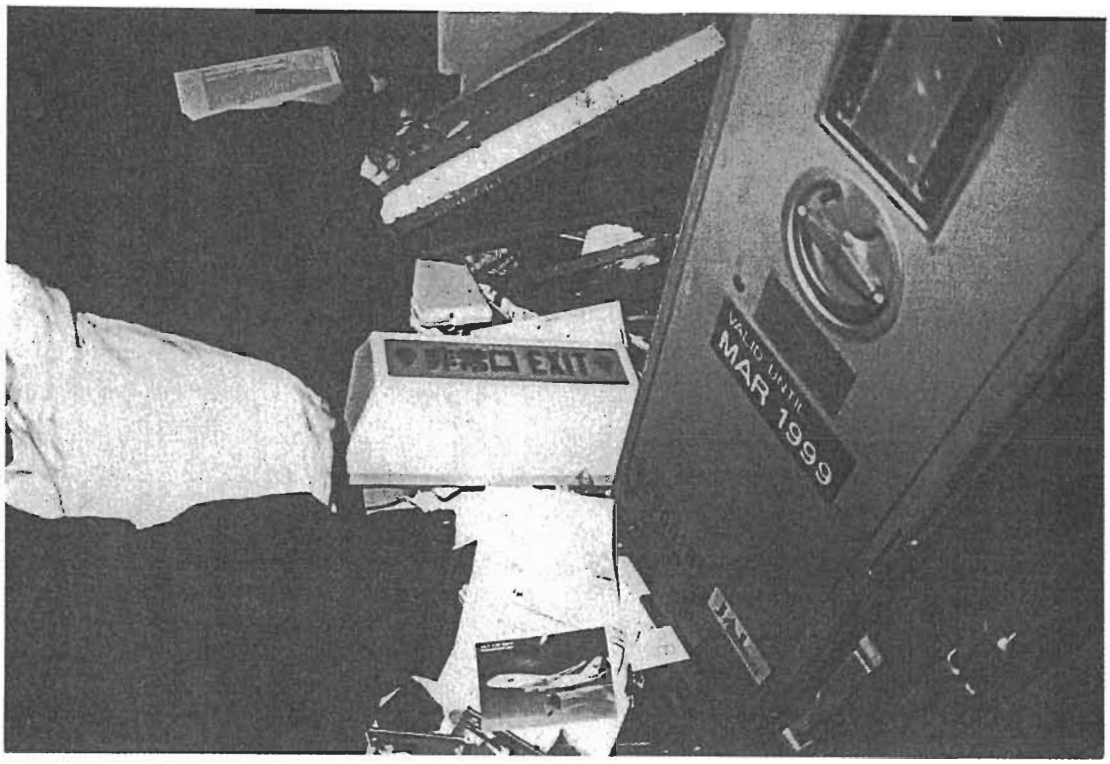
Photograph 1　Scatters in the Aft Galley



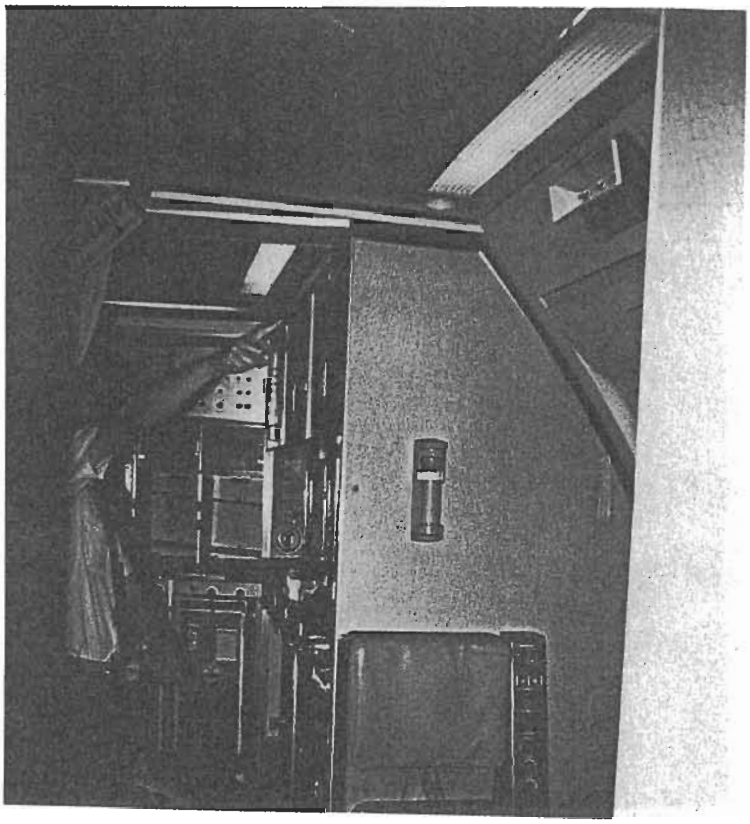
Photograph 2　Toppled Mealcarts in the Aft Galley



Photograph 3　Separated Emergency Exit Light Cover (L4 Door)



Photograph 4　Emergency Exit Light without Cover (L4 Door)



Recordings of DFDR and ADAS

The following parameters are presented as plotted in Appendix 1.

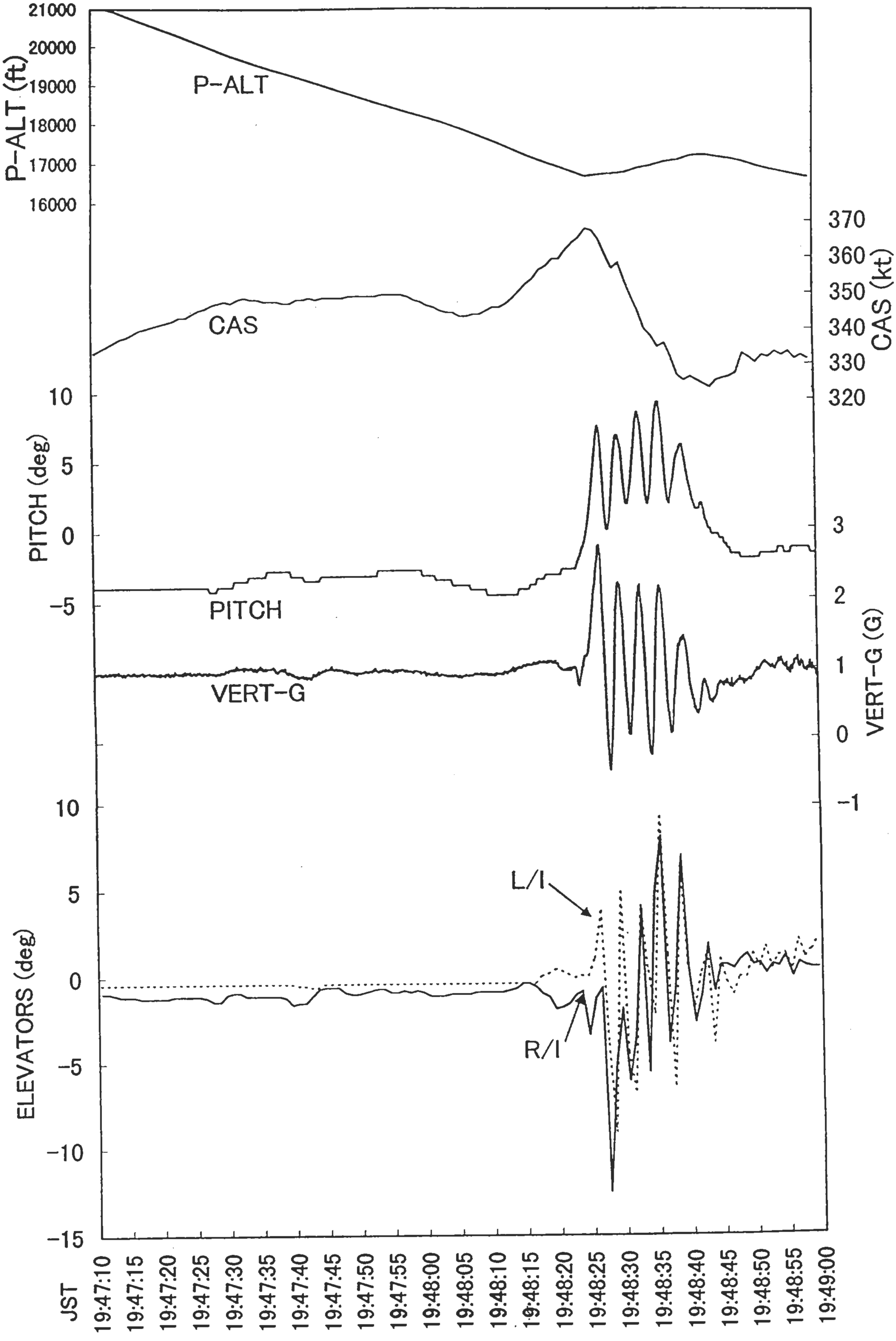
(DFDR Parameters)

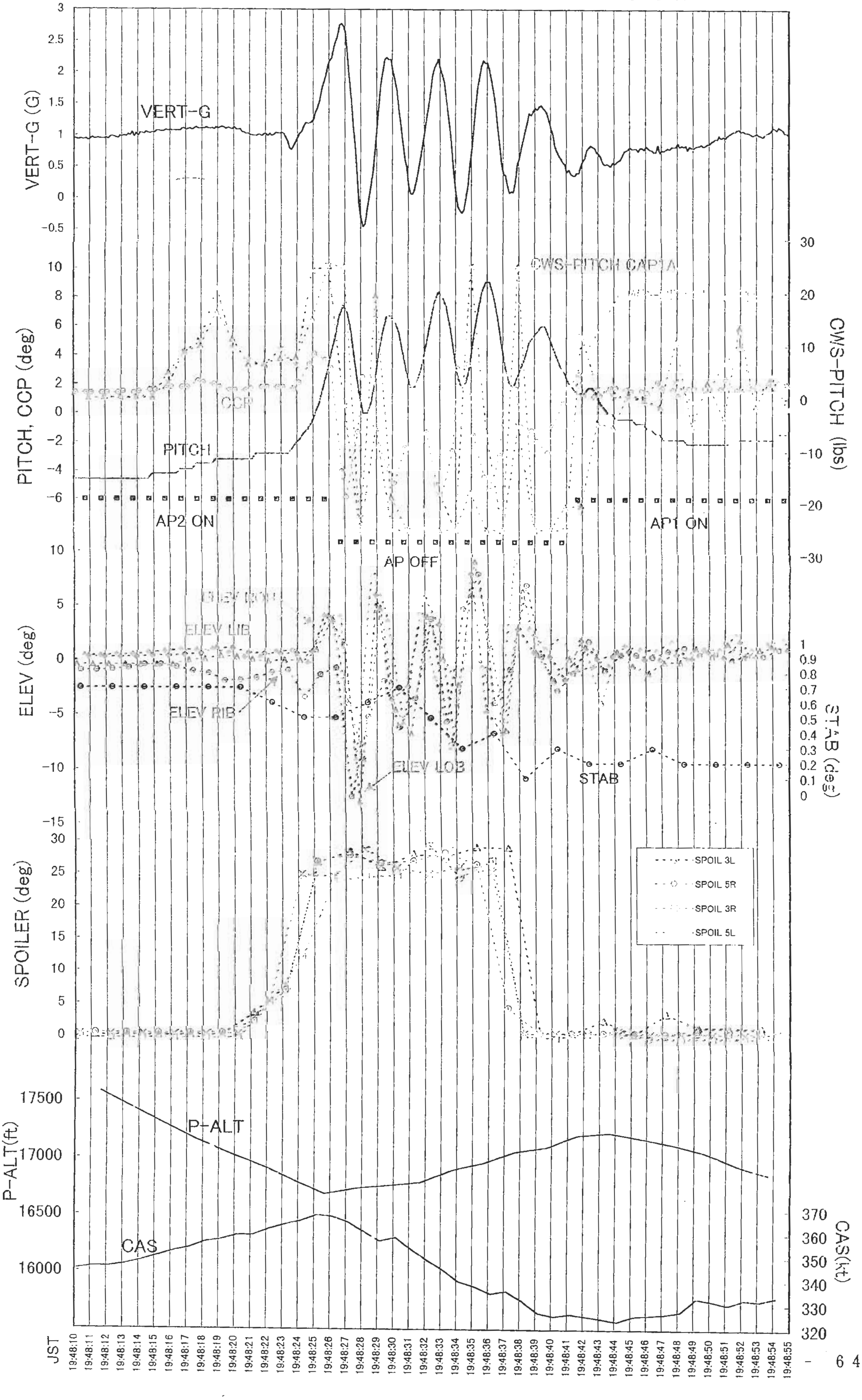
P－ALT	: Pressure Altitude
CAS	: Computed Air Speed
VERT－G	: Vertical Acceleration
MGHD	: Magnetic Heading
PITCH	: Pitch Attitude
AP	: Autopilot Status
ELEV	: Elevator Position
ELEV LIB	: Left Inboard Elevator Position
ELEV RIB	: Right Inboard Elevator Position
ELEV LOB	: Left Outboard Elevator Position
ELEV ROB	: Right Outboard Elevator Position
STAB	: Stabilizer Position
SPOILER	: Spoiler Position

(ADAS Parameters)

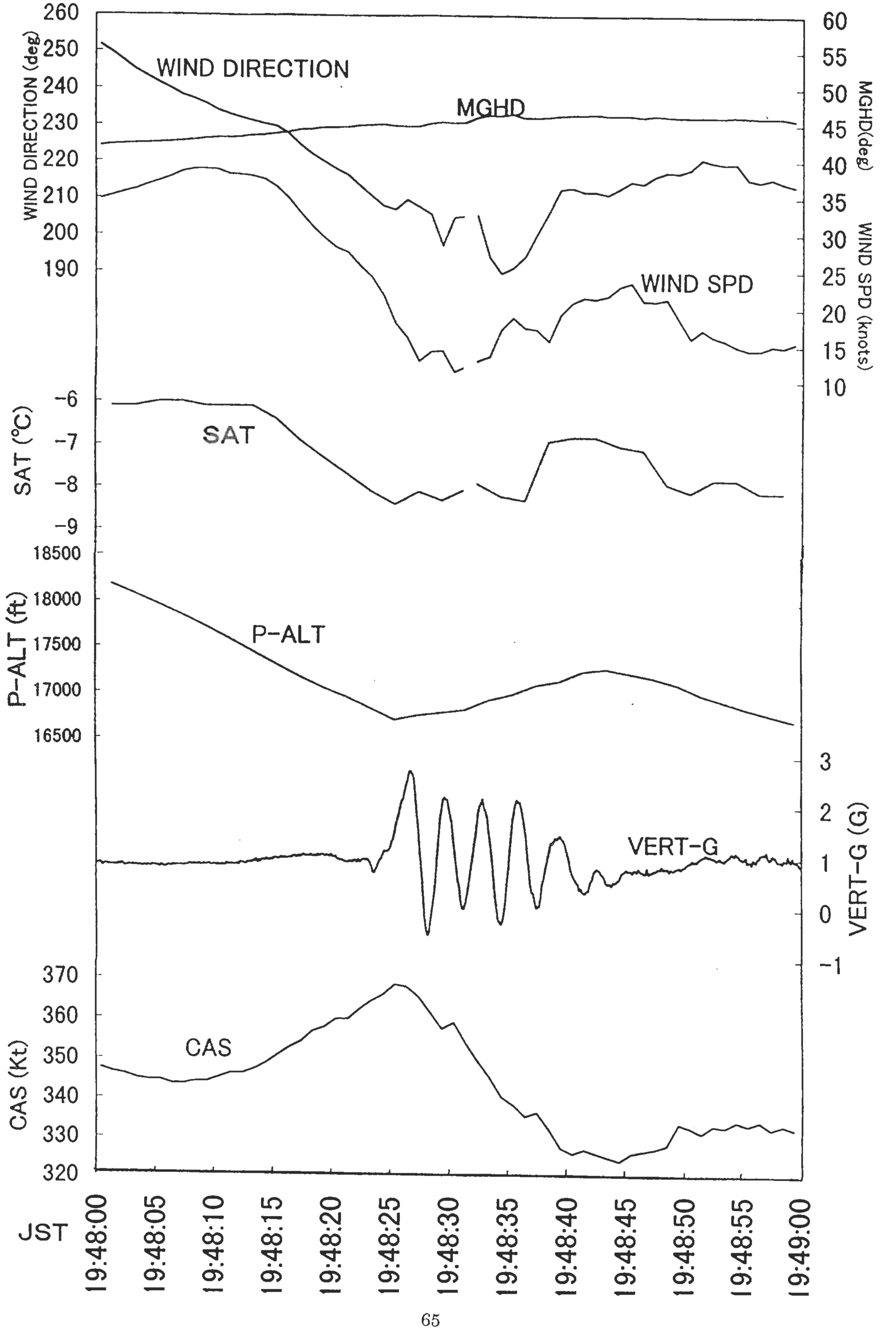
CWS－PITCH	: Control Column Force(Captain Side)
CCP	: Control Column Position
WIND DIR	: Wind Direction
WIND SPD	: Wind Speed
SAT	: Static Air Temperature

DFDR (P-ALT, CAS, PITCH, VERT-G, ELEV)




VERT-G (G)
VERT-G
PITCH, CCP (deg)
CWS-PITCH (lbs)
CWS-PITCH CAP1A
CCP
PITCH
AP2 ON
AP1 ON
AP OFF
ELEV (deg)
STAB (deg)
ELEV ROB
ELEV LIB
ELEV RIB
ELEV LOB
STAB
SPOILER (deg)
SPOIL 3L
SPOIL 5R
SPOIL 3R
SPOIL 5L
P-ALT(ft)
P-ALT
CAS(kt)
CAS
JST

DFDR & ADAS (WIND, SAT) PARAMETERS



APPENDIX 2

Numerical Analysis of the Pitch Oscillations (summary)

A numerical analysis of the pitch oscillations was carried out by using DFDR data, ADAS data and equation of the aircraft motion.

Concerning methods of analyzing the pitch angle's original response to the control column deflections, values of the pitch angle should fundamentally be estimated from values of the control column angle. Values of the pitch angle, however, were recorded four times per every second on the DFDR compared to values of the control column angle which were recorded two times per every second on the ADAS. Therefore, it was considered that more precise estimation would be expected if the response is obtained by reverse estimation in such a way that values of the control column angle are estimated by using the pitch angle as a starting variable, and so this procedure was adopted.

Outline of the numerical analysis methods is as follows.

(1) The time when each parameter was recorded on the DFDR/ADAS was compensated by averaging time delay variations on the data bus from the sensor to the time the data is recorded on the DFDR/ADAS based upon the document from the DFDR manufacturer.

The ADAS data was compensated by comparing the time difference in the records of vertical acceleration on the DFDR/ADAS. In addition, a time lag between the DFDR and ADAS data imparted by the difference of the number of recording word slots in each subframe (1 second) of the DFDR/ADAS was compensated.

(2) Data used in the flight simulator were mainly utilized as the stability coefficient.

(3) The airframe was assumed to be a rigid body; and basic data such as mass property provided by the manufacturer were used.

Further, the aircraft weight and C.G position were assumed to be the same conditions as those around the time of the accident.

(4) Concerning the time lag between the control column deflections and the responsive movement of the elevators as well as the response characteristics of the LSAS, data provided by the manufacturer were used.

(5) Concerning the motion of the aircraft, only the pitch motion was taken into consideration because fluctuations of roll angles and heading angles were negligibly small at the time of the accident.

(6) Concerning the sustained winds, since the vertical wind contribution was

assumed minor in the process of the data analysis, the longitudinal winds shown in Appendix 3 were taken into consideration.

(7) Although the MD-11 has four elevators, these were treated as one piece of elevator in this numerical analysis.

(8) Concerning the speed brakes (spoilers), since the data were roughly recorded every two seconds, the timing when the speed brakes were deployed was estimated by studying changes in the vertical acceleration and the test data provided by the manufacturer.

Based upon the above assumptions, the motion of the aircraft was numerically analyzed by carrying out a numerical computation with the equation of the aircraft motion during one minute time interval starting from 1947:55. As the result of the numerical analysis, pitch angle used as the initial value, estimated vertical acceleration, estimated CAS and estimated pressure altitude compared respectively with those recorded on the DFDR (drawn by the broken line) are shown in Figure A2-1 of this appendix.

As the results of the numerical analysis well correspond to the recordings of the DFDR data, the assumption that the vertical wind contribution was minor is considered proper.

Further, comparison between the estimated values of the control column angle and those recorded on the ADAS (drawn by the broken line) is shown in Figure A2-2 of this Appendix. Since the estimated values nearly correspond to the ADAS data, it is estimated by tracing the result of the numerical analysis in opposite direction that the pitch oscillations at the time of the accident occurred corresponding to the control column deflections.

Based upon the following reasons, it is estimated that the movements of the control column were caused by the pilot controls.

(1) The pitch oscillations occurred while the aircraft was being manually controlled, and the LSAS driven elevator movement feedback is not provided to the control column.

(2) The CWS PITCH (parameter on the ADAS representing the Captain side's control column force) showed that a force was exerted on the control column during the pitch oscillations.

In addition, it is estimated that the longitudinal stability characteristics of the aircraft contributed to the occurrence of the pitch oscillations.

Further, it is noticeable that the pitch oscillation was dampen in conjunction with decrease in the control column deflections after the pitch oscillations repeated.

Figure A2-1 Comparison between Numerical Analysis Results and DFDR data

Actual Line: Results of Numerical Analysis

Broken Line: Data recorded on the DFDR

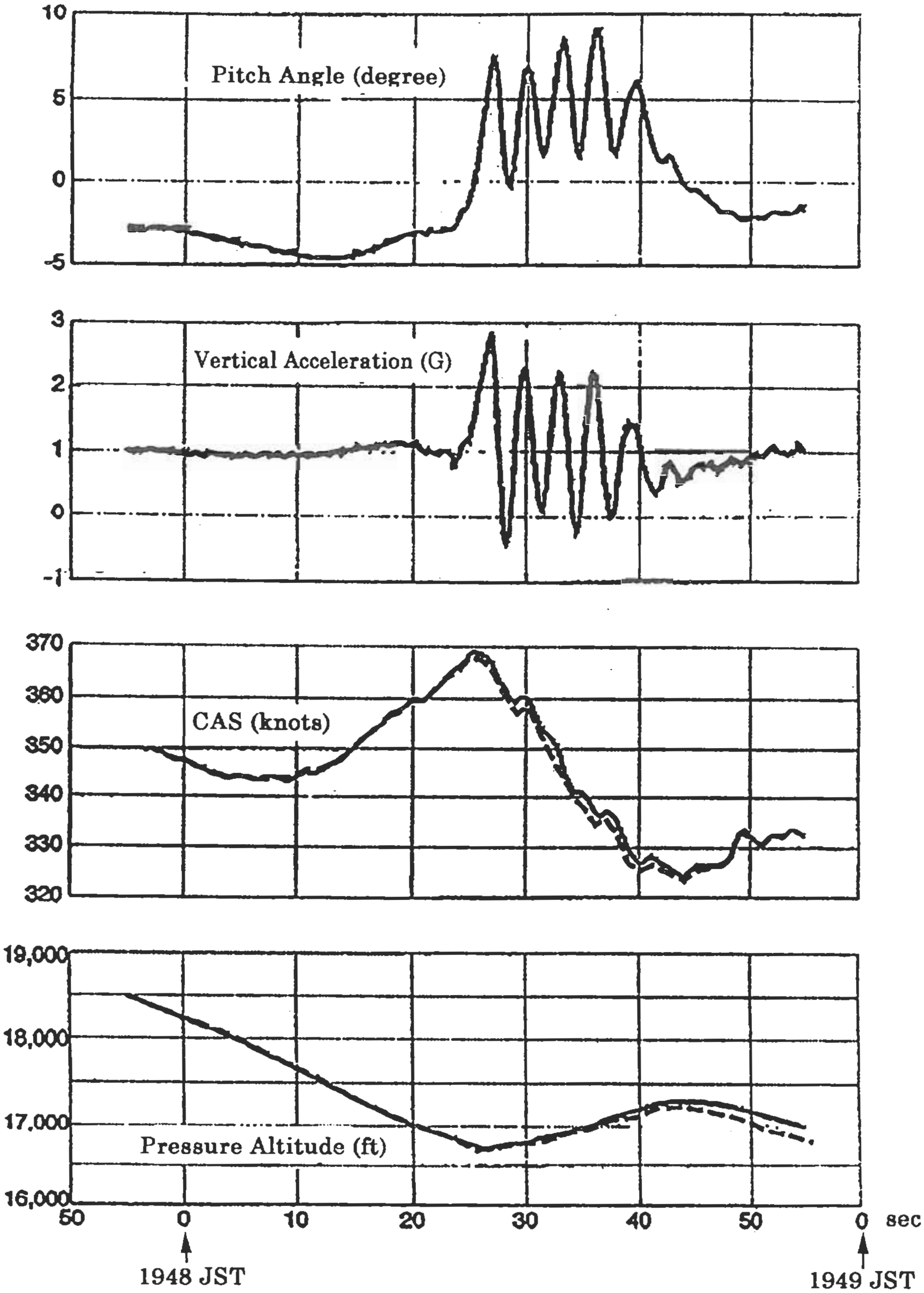
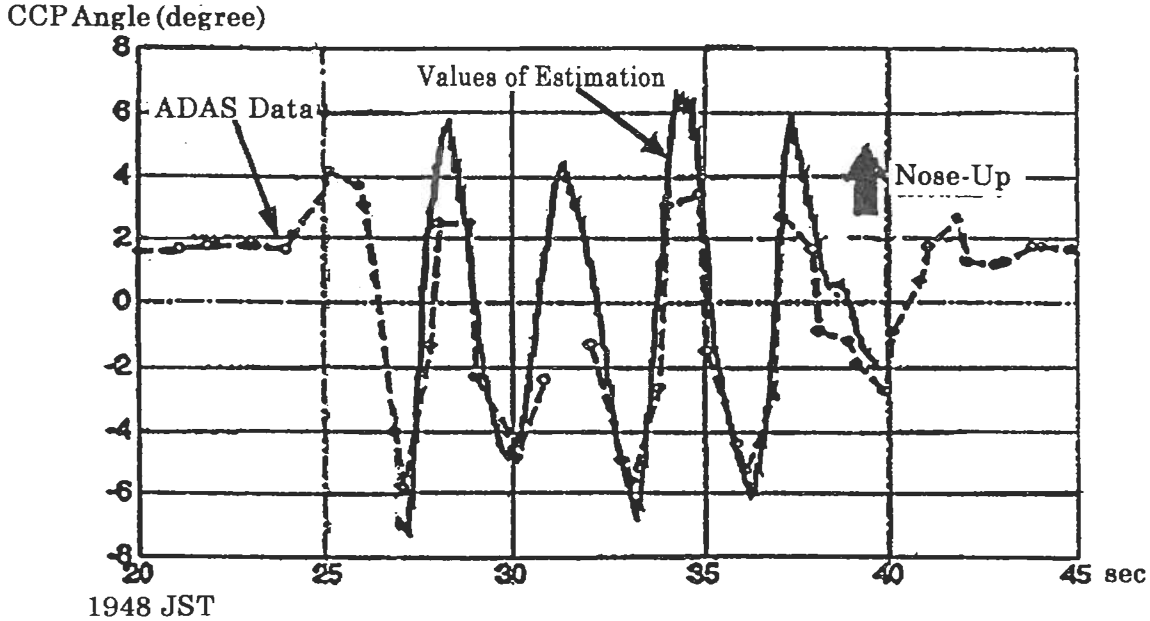


Figure A2-2 Comparison between Estimation and ADAS Data of Control Column Position (CCP)

Actual Line: Results of Numerical Analysis

Broken Line with Open Circle: Data recorded on the ADAS



Variations in the winds that acted on the aircraft

Although the wind speed/direction data were recorded every second on the ADAS, an one second data (one subframe) was lost due to the occurrence of an "ADAS data shedding" during the pitch oscillations. Therefore, the longitudinal wind variations in the direction of the aircraft heading that acted on the aircraft around the time of the accident were estimated by using the data of Ground Speed (data with directions on the ADAS), CAS, Pressure Altitude, SAT and Pitch Angle recorded on the DFDR and ADAS instead of using the wind data on the ADAS.

The wind speeds (vector) that acted on the aircraft were obtained from the vector subtraction between the Ground Speed (GS) and True Air Speed (TAS). In this case, the TAS was estimated by correcting the SAT and the Pressure Altitude for the CAS and assuming that the aircraft's side slip can be negligible. At the same time, the effects of the aircraft's rotations around all of the three axes were corrected.

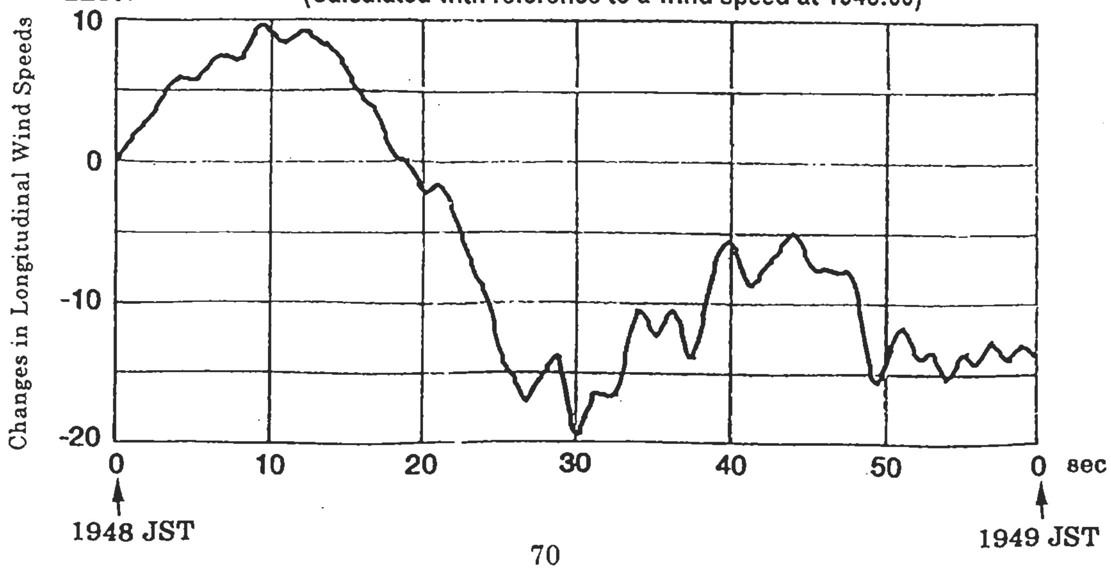
Further, the wind speed in the direction of the aircraft heading was obtained by calculating angles between the GS and TAS.

Variations in the longitudinal wind speed in the direction of the aircraft heading were calculated with reference to a wind speed at 1948:00 JST, and the result is shown in Figure below.

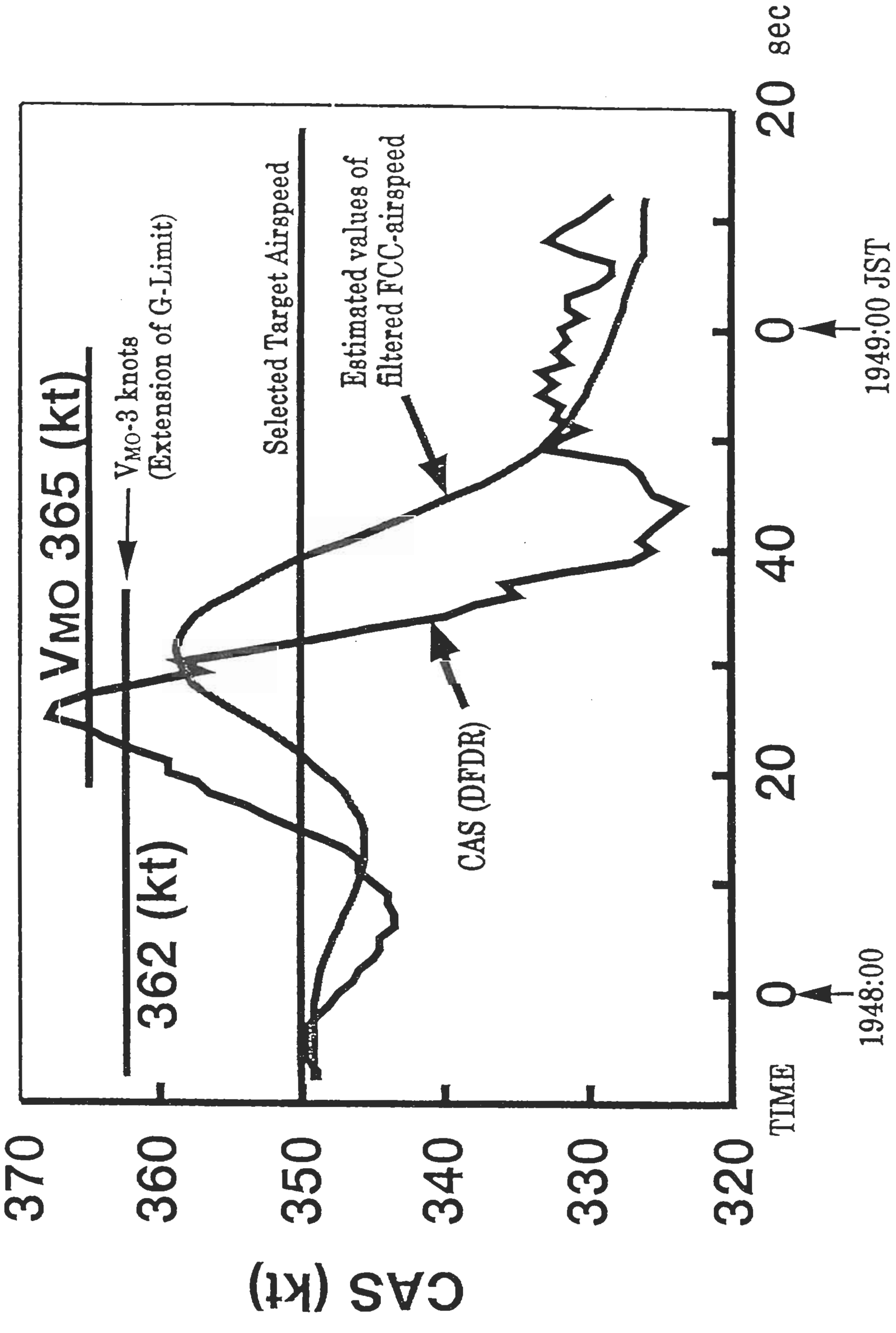
The Figure shows that the tail wind once increased and then decreased rapidly, which equals to the fact that the head winds increased against the aircraft. The rate of variations in the wind speed reached approximately 1.7〜2.8 knots/sec. It is estimated that the rapid changes in the wind speed resulted in the abrupt increase in the CAS.

In addition, it was difficult to estimate vertical wind activity with a high degree of accuracy because the Angle of Attack (AOA) data on the ADAS were suspected. It is, however, considered that the vertical wind contribution to the accident can be negligible based upon the numerical analysis shown in Appendix 2.

Estimated Longitudinal Wind Speed Variations in the direction of the Heading
(Calculated with reference to a wind speed at 1948:00)



Diagrammatic Chart of a Relationship between the CAS and the Estimated Values of Filtered FCC-Airspeed



Estimation of Vertical Acceleration sustained by the Cockpit and the Aft Galley

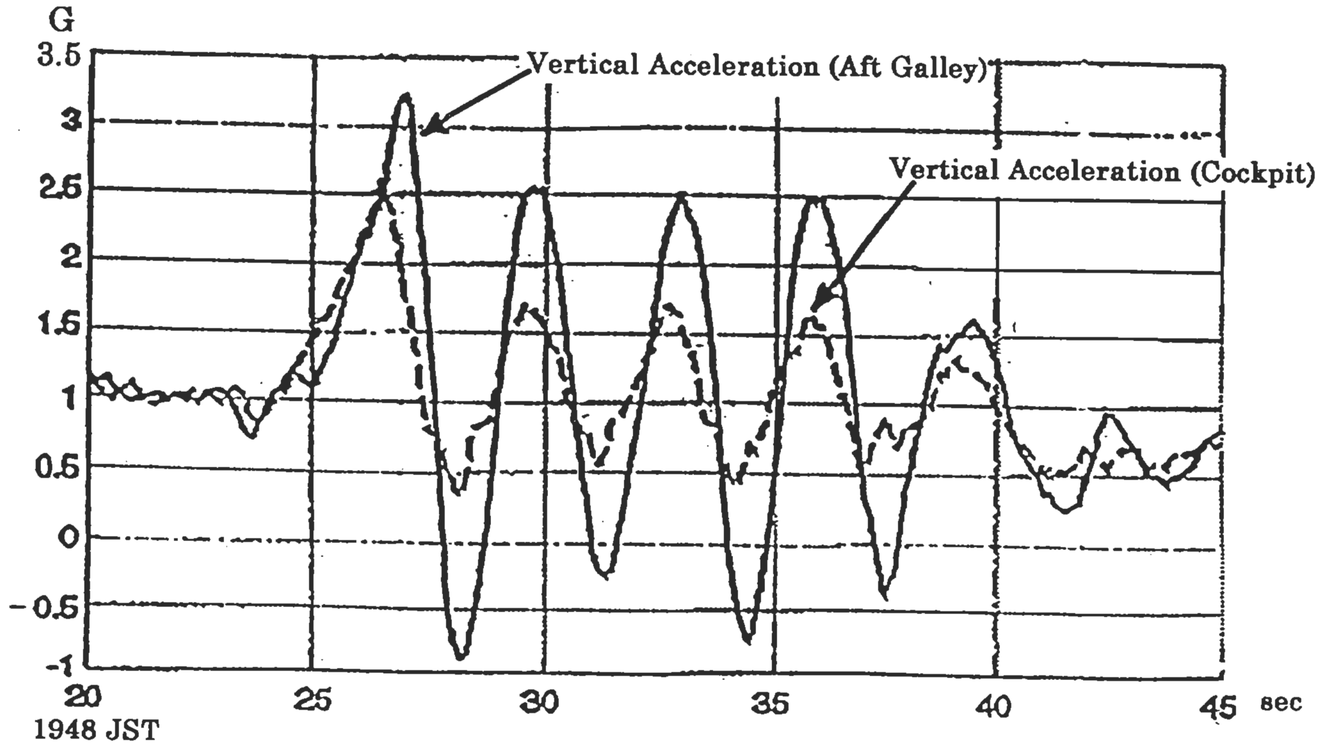
Based on the DFDR data and so on, a vertical acceleration which was sustained by the cockpit and the aft galley around the time of the accident was estimated.

The method of the estimation was as follows; First, values of vertical acceleration at the C.G. of the aircraft (assumed to be 29.5%) were calculated from those recorded on the DFDR, and then the amount of change in the vertical acceleration associated with the change in the aircraft's angular movement and the difference in the positions on the airframe was corrected by using the angular acceleration around the C.G. and the distance (parallel to the water line of the aircraft) between the CG and the cockpit/aft galley.

For calculation, the airframe was assumed to be a rigid body. In addition, the angular acceleration was estimated only from the pitch angle data, taking the pitch angle into consideration as the attitude angle because fluctuations of the heading angle and roll angle at the time of the accident were minor.

The result of the estimation is shown below as graphical data.

Estimated Vertical Acceleration sustained by the Cockpit and the Aft Galley



Representative Examples of Accident / Incident Regarding In-Flight Upsets of MD-11 Airplane

(1) China Airlines (December 7, 1992)

Synopsis: The aircraft encountered moderate turbulence while in cruise flight. The autopilot was disconnected and the airplane subsequently departed controlled flight.

Location: At 33,000 ft above sea level approximately 35 miles northeast of Shimizu navigational fix, Japan.

Injuries: None

Damage to Aircraft: The aircraft sustained damage to the elevator skin assemblies.

References: The seat belt sign was turned on prior to the accident.

(2) China Eastern Airlines (April 6, 1993)

Synopsis: The aircraft had an inadvertent deployment of the leading edge wing slats. Violent pitch oscillations occurred despite the pilot's recovery actions.

Location: 950 miles south of Shemys, Alaska, the U.S.A

Injuries: 2 passengers were fatally injured, 7 crew members and 53 passengers were seriously injured and 96 passengers sustained minor injuries.

Damage to Aircraft: None.

References: The seat belt sign was not turned on at the time of the accident.

(3) American Airlines (July 13, 1996)

Synopsis: With back pressure on the control column during descending, the autopilot was disengaged. The aircraft abruptly pitched nose up.

Location: Westerly, Rhode Island, the U.S.A.

Injuries: A passenger in the lavatory was seriously injured. A second passenger and 2 crew members sustained minor injuries..

Damage to Aircraft: None.

APPENDIX 6

Major Actions taken by manufacturer and airlines before the accident

1. McDonnell Douglas

There had been three occurrences (accident/incident) similar to the accident during a period between 1993 and 1996. Reviewing these occurrences, McDonnell Douglas has taken such actions as to issue All Operators Letter (AOL), revise FCOM, hold a High Altitude Handling Characteristics meeting and add an LSAS pitch rate damper (PRD) to improve the MD-11 high altitude stability characteristics.

The following are major actions taken by McDonnell Douglas;

(1) September 24, 1993

AOL 11-086 was issued, in which the letter informed operators of two occurrences of pitch upsets in severe turbulence encountered by MD-11 aircraft (China Airlines and China Eastern Airlines) and called attention to operators.

(2) November 29, 1993

FCOM Temporary Revision 2-550 was issued, in which revised the SEVERE TURBULENCE procedure to incorporate operational procedures discussed in the above AOL 11-086 and added procedures for closely monitoring AP operation in turbulence and the following "CAUTION";

① DO NOT ATTEMPT TO OVERPOWER THE AP WITH CONTROL FORCES. CARE MUST BE TAKEN NOT TO OVER CONTROL.

② NOTE: Longitudinal control forces at high altitude will be lighter than those which the pilot experiences at low altitude due to attitude effects and aft CG.

③ When the AP is off, use the minimum control inputs to fly attitude and allow the LSAS to maintain the aircraft attitude by relaxing pressure on the control column whenever possible.

(3) March 1, 1994.

The above CAUTION note was placed in the Supplemental Procedure section of the Severe Turbulence and/or Heavy Rain Injestion in Volume II of the MD-11 FCOM as of March 1, 1994 following two accidents (China Airlines on December 7, 1992 and China Eastern Airlines on April 6, 1993) and called attention to operators.

(4) June 15, 1994

In view of the accident/incidents attributed to the MD-11 high altitude control characteristics, an "MD-11 High Altitude Handling Qualities Meeting" was held at Long Beach, California for operators to recommend the following operational procedures.

① When encountering high altitude upsets, recovery from the upset with the AP operation.

② Never exert excessive pressure on the control column with the AP engaged.

③ If manually control the aircraft, slowly and smoothly take over control with the minimum control inputs.

④ Conduct not only class room training but also simulator training.

(5) July 1, 1994

AOL 11-086A was issued to amend the AOL 11-086, specifying contents regarding the AP disconnection.

(6) May 17, 1995.

An "MD-11 Flight Operations Seminar" was held at Costa Mesa, California. The seminar was dedicated to "MD-11 High Altitude Handling characteristic", which included MD-11 High Altitude Handling Qualities and Upset Recovery Training. (Refer to Appendix 9)

In addition, other two "MD-11 Flight Operations Seminar" were held at Costa Mesa on October 26, 1993 and on October 23, 1996.

(7) January 18, 1996 (Issuance of Service Bulletin No. MD-11-22-016)

This service bulletin provided instructions to update FCC software per Honeywell incorporated Service Bulletin 4059001-22-SW17.

The SB 4059001-22-SW17 included software modification to add a Pitch Rate Damper to the LSAS.

(8) October 1, 1996.

AOL 11-131 was issued, in which the letter informed operators of the outline of accident involving American Airlines MD-11 occurred on July 13, 1996 and advised of a forthcoming revision in the MD-11 FCOM, regarding how the AP disconnection with force on the control column affect the flight characteristics, to call the following attentions to operators.

(Refer to Appendix 10)

① Cautions when disengaging AP.

Pilots never exert force on the control column when disengaging the AP.

② Cautions in the Capture Mode of the AP.

2. Japan Airlines

The following are major actions taken by Japan Airlines (JAL) with respect to the MD-11.

(1) August, 1993

JAL's initial pilot training for the MD-11 was started.

(2) April 1, 1994

The JAL MD-11 Aircraft Operating Manual (AOM) was revised to reflect the contents of the CAUTION note which was placed in the MD-11 FCOM as of March 1, 1994.

(The JAL MD-11 was inaugurated a service)

(3) June 15, 1994

The JAL attended an "MD-11 High Altitude Handling Qualities" meeting held by McDonnell Douglas.

In addition, the JAL attended three "MD-11 Flight Operations Seminar" which were held by McDonnell Douglas at Costa Mesa on October 26, 1993, May 17, 1995 and October 23, 1996

(4) July 1, 1994 (Revision to the JAL AOM)

Based on the result of the above MD-11 meeting, the JAL AOM was revised to add descriptions regarding conditions of the AP disconnection and cautions in manually controlling the aircraft in high altitude during severe turbulent flight.

(5) July 1, 1995 (Revision to training materials for MD-11 pilots)

Pilot Flight Training Guide was revised to add "Note 4. Cautions when manually controlling the aircraft in high altitude" and "Note 5. The reasons that pilot should not override the AP " into an item 9 "In the case of encountering severe turbulence" in Section 1-8 "CRUISE".

This revision was made voluntarily by the JAL based on the result of the "MD-11 High Altitude Handling Qualities meeting".

(Refer to Appendix 8)

(6) July 7, 1995 (Modification to the flight simulator)

The MD-11 flight simulator was modified to precisely represent the MD-11 high altitude flight characteristics, based on data provided by McDonnell Douglas.

(7) October, 1995 (The beginning of simulator training, based on the result of the MD-11 Flight Operations Seminar)

The JAL started the simulator training on the MD-11 high altitude flight characteristics in type transition training and annual recurrent training for Captain and First Officer. The contents of the training include how to use the AP system or cautions on manual control when recovering from abrupt upsets generated in the simulator assuming that the aircraft encounter a high altitude windshear.

In addition, modifications to all of the MD-11's FCC software were completed by March, 1996.

(8) December, 1996 (the receipt of AOL 11-131 issued in October 1, 1996)

The AOL 11-131 was issued by McDonnell Douglas to inform operators of the pitch-up event involving American Airlines' MD-11 and advise them of a forthcoming change in the FCOM.

The JAL did not make an in-house notification of the AOL 11-131 because the contents of the AOL had already been reflected in the JAL MD-11 AOM and training syllabus.

Excerpts from the JAL's AOM (Aircraft Operating manual) [Page 4-2-(14) 3/28/96]

(NOTE by the AAIC)

The JAL's AOM is produced by translating the McDonnell Douglas's FCOM into Japanese with the JAL's devised some English words mixed.

Therefore, the AAIC has prepared the following English translation for the captioned extract of the JAL's AOM combining the English words used by JAL.

4-2-7 Flight in Areas of Severe Turbulence

NOTE

In areas of turbulence, fly the FMS optimum attitude as long as possible. Buffet margin and economy will be enhanced. Descent if necessary to improve buffet margin.

Turbulence Penetration Speed...............290 TO 305 KIAS 0.80 TO 0.82 MACH, WHICHEVER IS LOWER

NOTE

Below an altitude of 10,000 feet, 250 KIAS or CLIMB SPEED, whichever is higher, may be used.

ENG IGN OVER Switch..OVRD ON

Push ENG IGN OVRD switch and check OVRD ON light illuminates.

Auto Throttles...OFF

Push either ATS disconnect switch and check the ATS OFF display on the PFD

NOTE

Adjust throttles only if necessary to correct excessive airspeed variation or to avoid exceeding redline limits. Do not chase airspeed.

Autopilot..MONITOR

Use the autopilot in turbulence. Closely monitor autopilot operation and be prepared to disconnect the autopilot only if the aircraft does not maintain an acceptable attitude.

If the autopilot disconnects, the pilot should smoothly take over control and stabilize the pitch attitude. Fly referring to the attitude indicator as the primary pitch reference; it will be unavoidable to sacrifice altitude to some extent. Disregard the Flight Director Pitch Bar. Do not trim manually.

After recovery, reengage the autopilot if possible. If the autopilot is engaged outside the capture zone of the FCP altitude, a new altitude will be automatically commanded and smoothly captured.

[Page 4-2-(15) (CAUTION below is dated as of 4/1/94)]

CAUTION

(1) Do not attempt to override the autopilot with control forces. This can cause the autopilot to disengage with too much control input, which could result in over control during recovery. Close attention must be paid not to over control.

(2) Pitch control forces at high altitude will be considerably lighter than those at low altitude due to altitude effects and aft CG.

(3) When the autopilot is off, use minimum inputs to control attitude, relax inputs on the control column as long as possible and maintain attitude by the LSAS.

.... Further parts are omitted ....

(Reference) The following CAUTION notes (JAN/10/94) described in the McDonnell Douglas's FCOM is for a comparison with the CAUTION notes above.

CAUTION

Do not attempt to overpower the autopilot with control forces. This can cause the autopilot to disengage with too much control input, which could result in over control during recovery. Every attempt should be made not to over control.

Longitudinal control forces at high altitude will be lighter than those which the pilot experiences at low altitude due to altitude effects and aft CG.

When the autopilot is off, use minimum control inputs to fly attitude and allow the LSAS to maintain attitude by relaxing pressure on the control column whenever possible.

Excerpts from the JAL's AOM Supplement
[Page S-2-3-4 (1) 7/1/94]

(NOTE by the AAIC)

The JAL's AOM is written in Japanese with some English words mixed.

Therefore, the AAIC has prepared the following English translation for the captioned JAL's AOM Supplement combining the English words used by JAL.

S2-3-4 Flight in Areas of Severe Turbulence

1. General

Basic items concerning flight in severe turbulence are as follows;

1) Observe a Turbulence penetration Speed
2) Make an ENG IGN OVERRIDE Switch to "OVRD on"
3) Make an Auto Throttle System off
4) Monitor an operation of the autopilot
5) Increase a Bleed Demand and increase a Surge Margin of the engines

Supplemental descriptions are given below concerning two items, i.e. conditions that the autopilot is automatically disengaged and remarks on manual control at high altitude in case of the autopilot disengagement during turbulent flight.

2. Conditions that the autopilot is automatically disengaged

The FCC gets the autopilot to be disengaged under conditions below;

(1) Vertical G exceeds $1\pm0.6\sim1\pm1.4$

(depending on the pitch rate when the event occurs.)

(2) Roll rate exceeds 10 degrees/second.

(3) Bank Angle exceeds 60 degrees.

(4) Position of each control surface differs from that commended by the autopilot due to Pilot's override control etc.

These result in the disengagement of the autopilot depending on the strength of turbulence.

3. Remarks on manual control at high altitude

A manual control is in general difficult because of the reduction of stability at high altitude, and further pitch control force tends to result in overcontrol because the control force is considerably light compared to that at low altitude due to the effect of altitude and aft CG. Accordingly, make input minimum to control attitude, relax input on the control column as possible as it can be and it is preferable to maintain attitude by the LSAS.

As a result, take the following points into consideration when a severe turbulence is encountered.

(1) Keep the autopilot engaged as long as possible, and do not override it.

(2) If the autopilot is disengaged, set desired attitude and relax control inputs.

(3) Swiftly reengage the autopilot

(4) Lower the altitude if possible.

Excerpts from the JAL's Pilot Flight Training Guide
[Page 1-8 (3) (NOV 01 96)]

(NOTE by the AAIC) The JAL's AOM is written in Japanese with some English words mixed. Therefore, the AAIC has prepared the following English translation for the captioned Pilot Flight Training Guide combining the English words used by JAL.

(9) At the time when a severe turbulence is encountered.

Recommended procedures are as follows;

ENG IGN OVED Switch	ON
ATS	OFF
TURBULENCE PENETRATION SPEED	OBSERVE
ENG.WING AND TAIL ANTI-ICE	ON
ECON Switch (Upper Air Con PNL)	OFF

NOTE 1

TURBULENCE PENETRATION SPEED

At or Above 10,000 ft	290-305 kt or Mach .80-.82
Below 10,000ft	Greater of 250kt or O/RET.FLAP/ Vmin+10kt when SLATs are used.

NOTE 2

When ECON Switch is turned off, Bleed Air turns High Bleed (If Anti-Ice is ON, it has been already High Bleed), Recirculation Fan stops and Air Con Pack begins its Full operation. (Normally, when Air Con sys is set Auto, rotation of the Recirculation Fan reduces operation of the PACK). As a result, the amount of Compressor Bleed Air from the Engines increases, leading to the increase in Eng Stall Margin.

When ECON Sw stays Off, the state is indicated on EAD.

NOTE 3

There is a possibility that the autopilot is disengaged depending on the strength of turbulence.

The FCC gets the autopilot to be disengage under conditions below;

1) Vertical G exceeds $1\pm0.6\sim1\pm1.4$
(depending on the pitch rate when the event occurs.)
2) Roll rate exceeds 10 degrees/second.
3) Bank Angle exceeds 60 degrees.
4) Position of each control surface differs from that commended by the autopilot due to Pilot's override control etc.

[Page 1-8 (4) (JUL 01 95)]

NOTE 4

Remarks on manual control at high altitude.

A manual control is in general difficult because of the reduction of stability at high altitude, and further pitch control force tends to result in overcontrol because the control force is considerably light compared to that at low altitude due to the effect of altitude and aft CG. Accordingly, make input minimum to control attitude, relax input on the control column as possible as it can be and it is preferable to maintain attitude by the LSAS.

As a result, take the following points into consideration when a severe turbulence is encountered.

(1) Keep the autopilot engaged as long as possible, and do not override it.
(2) If the autopilot is disengaged, set desired attitude and relax control inputs.
(3) Swiftly reengage the autopilot.
(4) Lower the altitude if possible.

NOTE 5

The reason that the autopilot should not be overriden.

In the case of elevators, the autopilot (in the case that AP 1 is engaged) normally controls the Left Inboard Elevator, and other three elevators are driven through Followup Cables. But if the autopilot is overriden, those three elevators are driven not by Followup Cables but by Manual Control inputs, and the aircraft does not follow the autopilot command when inputs different from the autopilot command are applied, which results in causing larger deflection of the elevator controlled by the autopilot. At this point, if the autopilot is disengaged under the conditions of NOTE 3 above, the elevator suddenly follows the Manual Control resulted in producing a large G load on the aircraft.

Excerpts from Materials distributed at the MD-11 Flight Operations Seminar
(McDonnell Douglas held the seminar at Costa Mesa, CA, on May 17, 1995)

MD-11 High Altitude Stability Enhancement

Recovery From High Altitude Upset

DAC Procedures

1. If Autopilot Remains Engaged
   - Monitor for Statisfactory Recovery
   - If Recovery Not Satisfactory

     Disengage the Autopilot and Return to a Satisfactory Attitude

     Reengage the Autopilot If Possible

Note: <u>NEVER</u> Override the Autopilot

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MD-11 High Altitude Stability Enhancement

Recovery From High Altitude Upset (Continued)

2. If Autopilot Disengages
   - Return to a Satisfactory Attitude
   - Reengage the Autopilot If Possible
3. Adjust Airspeed and/or Altitude as Necessary

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AOL
ALL OPERATORS LETTER | FLIGHT OPERATIONS

October 1, 1996
FO-AOL-11-131

To: All MD-11 Operators

Subject: PITCH-UP FOLLOWING AUTOPILOT DISENGAGEMENT

Applicable to: All MD-11 Aircraft

ATA Chapter No.: 22-11, Pitch Control & 22-10, Autopilot

Reason: To inform operators of an MD-11 pitch-up event after the autopilot was disengaged during descent, and to advise of a forthcoming change in the MD-11 Flight Crew Operating Manual, systems description.

While descending rapidly through Flight Level 250, the First Officer, as the pilot flying (PF), thought that the Autopilot was not responding to nose-up pitch commands from the Vertical Speed (V/S) control wheel. The autopilot was disconnected, and the aircraft pitched up abruptly causing injury to flight attendants and passengers.

The Digital Flight Data Recorder (DFDR) data and operational tests revealed that the autopilot and its autotrim functions, the Longitudinal Stability Augmentation System (LSAS), and the Flight Control Computers (FCC) all functioned normally.

Analysis of the DFDR data showed that with the autopilot engaged in the Level Change mode, the aircraft was descending from FL 350 to FL 240 at Mach 0.84 with speed brakes deployed. The first officer became concerned about capturing the selected altitude because of the high descent rate, and commanded a level-off using the Vertical Speed mode. After repeated attempts to level off appeared to be unsuccessful, the speed brakes were retracted and the autopilot was disengaged. Immediately following the autopilot disengagement, the aircraft pitched up abruptly with a load factor increase of 2.3 g.

Further analysis of DFDR data showed that prior to moving the V/S wheel, the aircraft had begun to level off, because the load factor increased by about 0.2 g, which is the autopilot target to

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ensure a comfortable altitude intercept. Whenever the V/S wheel is moved, the Autopilot will cancel the capture mode, and will not re-engage in capture until the V/S wheel has come to rest for 2 seconds. The data showed that the autopilot was toggling between Vertical Speed mode and Altitude Capture mode due to repeated adjustments of the V/S wheel. The Altitude Capture mode was never engaged for more than one second, and repeated adjustments of the V/S wheel made the capture of the target altitude not possible.

The V/S intervention feature is intended to allow the pilot to intentionally fly through an armed altitude. For example, this would enable a glide slope capture from above. With autopilot 2 engaged, the autopilot commands only the right inboard (RIB) elevator for pitch control. The other three elevator surfaces are then "back-driven" through the follow-up cable system. In this incident the DFDR data showed that prior to disengaging the autopilot, all back driven elevator surfaces had followed the autopilot driven surface, indicating normal autopilot operation. The data also showed, however, that while the autopilot was still engaged, the back-driven elevators began to move away from the RIB elevator in the aircraft nose up (ANU) direction, indicating considerable pull force on the control column. If a pull force is applied when disengaging the autopilot, then all the autopilot-driven elevator surfaces will move rapidly in the pull force direction.

A computer simulation reproduced the pitch-up event described above, verifying the response of the elevators. The simulation substantiated that the response of the elevators during autopilot disengagement was the only factor in the pitch-up. There had been speculation that retraction of the speed brakes might have contributed to the pitch-up; Douglas' research indicates that this was not the case. In fact, retracting the speed brakes under these conditions will cause an aircraft nose down pitching moment. Both the DFDR and the simulation showed that the pitch-up was the direct result of disengaging the autopilot while exerting an ANU force on the control column.

The MD-11 Flight Crew Operating Manual (FCOM) cautions pilots not to exert force on the control column when disengaging the

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autopilot. Douglas will revise the FCOM to better explain the Capture Mode of the autopilot in the Systems Description, and to emphasize the impact of disengaging with force on the control column.

Should additional information be required, please submit your questions to Flight Operations Customer Service, Douglas Aircraft Company, 3855 Lakewood Boulevard, Mail Code: 94-26, Long Beach, California 90846-0001, fax: (310) 593-3471.

D. C. Shapiro
Director
Flight Operations

SRL/TJM:csl

APPENDIX 11-1

Proposals made by the AAIC

In line with this accident, the AAIC made "Proposals" to the Minister for Transport as follows. (Documents attached to these "Proposals" are omitted here.)

(1) September 5, 1997

SUBJECT: Proposals on the aircraft accident involving Japan Airlines' McDonnell Douglas MD-11, JA8580. (Proposal No. 10)

With respect to the subject above, the Aircraft Accident Investigation Commission proposes as follows in accordance with Article 22 of AAIC Establishment Law.

The AAIC has been pursuing an investigation and analysis of a comprehensive information, including meteorology, aircraft performance and pilotage, to probe the probable cause of the subjected accident which occurred over Shima peninsula on June 8, 1997.

As a result of the investigation up to now, it is possible to think that an abrupt violent pitch oscillations were attributed to precipitating a so-called PIO (Pilot Induced Oscillation), resulted from repeating the pilot-commanded elevator deflections after the autopilot was disconnected.

Immediate measures should be taken in order to preclude a recurrence of an accident attributed to the event above.

(2) March 5, 1999

SUBJECT: Proposals on the promotion of fastening seat belts at all times in operating aircraft. (Proposal No. 13)

With respect to the subject above, the AAIC proposes as follows in accordance with Article 22 of AAIC Establishment Law.

It is considered to be indispensable that persons on board should fasten their seat belts to secure their safety in the case that aircraft in operation experience upsets.

It is considered that contributing factors to the aircraft's upsets in operation would have been an encounter with a turbulence and so on. Investigation reports of the accidents made public by the AAIC, involving Air Transport Service Aircraft which encountered a turbulence, have reached 11 cases over the past 10 years.

In addition to the aforementioned accidents, in the cases of the accidents involving United Airlines Flight 826 which occurred over international water in the pacific ocean on December 28, 1997 (under investigation by the NTSB as the state conducting the investigation) and Japan Airlines Flight 706 which occurred over Shima peninsula, Japan, on June 8, 1997 (under investigation by the AAIC), it is considered to be likely that severe injuries sustained by persons on board were attributed to what they did not fasten their seat belts when encountering the aircraft's upsets.

On the other hand, in some cases, the aircraft's upsets will suddenly occur and the crew will be unable to anticipate the occurrence of such upsets in advance.

Accordingly, the AAIC proposes the Minister of Transport to require domestic air transport service companies to review necessary measures for ensuring an establishment of fastening seat belt at all times in order to prevent an accident attributed to what seat belts are not fastened.

Attachment: A list of the turbulence-related accidents which have occurred over the past 10 years. (The accidents under investigation are excluded.)

Major Actions taken by the Japan's Civil Aviation Bureau (JCAB) after the Accident

Upon receipt of Proposals No.10 made by the AAIC as of September 5, 1997, the JCAB issued "Director-General of Engineering Department Notification No.693" as of September 8, 1997 to the JAL, other seven Domestic Scheduled Air Transport Service companies and an International Non-scheduled Air Transport Service company to review and enhance the pilot's training for autopilot's characteristics of all type of aircraft operated by the companies and require them to report the results in an expeditious manner.

In addition, the JCAB issued "Director of Flight Standards Division Notification No.809" as of October 16, 1998 to nine Domestic Scheduled Air Transport Service companies and two International Non-scheduled Air Transport Service companies to require them to fully grasp weather information obtained before departure and during flight and to assure safety of passengers and flight crew by fastening seat belts in operating aircraft.

Further, upon receipt of Proposals No.13 made by the AAIC, the JCAB established a study committee in cooperation with the Association of Air Transport Engineering and Research to review the matters required to the promotion of fastening seat belts at all times in operating aircraft.

Actions taken by airlines, manufacturer and organization concerned after the accident

The captioned actions are as follows:

1. McDonnell Douglas

Actions initially taken by McDonnell Douglas was to call attention to operators regarding what pilot may not manually override the AP during flight in severe turbulence. Subsequently, the company has strictly enhanced the FCOM descriptions such as removal of condition limited in the Severe Turbulence and additional descriptions of the lessening control force at high altitude and what pilot will relax force on the control column if the AP disconnection due to overriding it results in pitch upset. Also the company has improved simulator training and enhanced video training materials.

The following are major actions taken by the company after the accident (including ongoing actions).

(1) June, 1997 FAA/ATA/DAC

Issuance of training materials regarding turbulence.

(2) June 25,1997 (Issuance of FCOM Temporary Revision 2-767, Refer to Appendix 12)

The following CAUTION was included in a temporary revision to the Supplemental Procedures section of the AFS in Volume II of the FCOM to call attention.

"Do not disengage the autopilot by making manual inputs to the control column and do not apply force on the control column when disconnecting the autopilot............"

(3) August 29, 1997 (Issuance of FCOM Temporary Revision 2-784, Refer to Appendix 12)

This revision replaced Temporary Revision 2-767 to revise the CAUTION concerning the AFS (Automatic Flight System) and change it to a WARNING as follow;

"If a force is applied to the control column while disengaging the autopilot, the aircraft will respond abruptly."

(4) December 2, 1997 (Issuance of FCOM Temporary Revision 2-826, Refer to Appendix 12)

This revision replaced Temporary Revision 2-784 to revise the WARNING for adding the following description.

"If an inadvertent autopilot disconnect occurs, the pilot must smoothly stabilize the aircraft attitude, releasing the flight controls, if necessary, until the aircraft motion dampens out."

(5) December 2, 1998 (Issuance of FCOM Temporary Revision 2-827)

Descriptions pertinent to "procedure during SEVERE TURBULENCE" were changed to be consistent with the AFS procedure.

(6) February 16, 1998 (Issuance of FCOM Temporary Revision 2-831)

Contents of this revision are the same as those of FCOM Temporary Revision 2-827.

(7) On-going

Developments of Video Tape for Ground Training regarding MD-11 High Altitude Handling and Upset Recovery Techniques.

(8) On-going

Implementation of MD-11 Motion Base Simulator to provide exercise in MD-11 High Altitude Handling and Upset Recovery Techniques.

2. Japan Airlines

The following are major actions taken by the company after the accident.

(1) June 9, 1997

A notification was issued by Senior Vice President of Cabin Attendant Division with respect to preventing recurrence of turbulence-related aircraft accident.

(2) June 19, 1997 (Issuance of "OPERATIONS INFORMATION MD-11-73")

An in-house notification with respect to cautions in controlling pitch attitude when the AP is disengaged.

(3) August 8, 1997 (Issuance of "AIRCRAFT OPERATING MANUAL BULLETIN No.68")

Section 4-7 "AUTOMATIC FLIGHT" was partially revised to add a CAUTION "Do not disengage the autopilot by making manual inputs to the control column" and "If a force is applied to the control column while disengaging the autopilot, the aircraft will respond abruptly."

(4) September 10, 1997 (Issuance of "Operations News No.486-(OEZ))

All of the JAL Flight Crew Member were informed by this issuance of the outline of Interim Investigation Report of the accident involving the JAL 706 MD-11 and Proposals issued by the AAIC.

(5) September 11, 1997 (Issuance of "Operations News No.485-(OEZ))

An in-house notification with respect to how the AP disconnection with force on the control column affect the flight characteristics.

(6) September 11, 1997

The JAL MD-11 flight crew member were informed by a notification issued by Vice President of Flight Crew (MD-11 Department) of Interim Investigation Report of the accident involving the JAL 706 MD-11 issued by the AAIC and cautions in controlling pitch attitude when the AP is disengaged.

(7) September 17, 1887 (Issuance of "AIRCRAFT OPERATION MANUAL BULLETIN No.70")

The "AIRCRAFT OPERATION MANUAL BULLETIN No.68" was abolished to change the CAUTION "Do not disengage the autopilot by making manual inputs to the control column, and if a force is applied to the control column while disengaging the autopilot, the aircraft will respond abruptly." into a WARNING.

(8) September 22, 1997

The progress which had been made by the JAL following receiving a Notification No.693 issued by Director-General of Engineering department of Civil Aviation Bureau of Japan (JCAB) as of September 8, 1997 with respect to reviewing and enhancing the pilot training for autopilot's characteristics of all type of aircraft owned by the company was reported to the Director-General.

(9) October, 1997

An advanced pilot training was introduced to enhance the training scenarios regarding how to recover from aircraft abnormal attitude and so on.

(10) October 24, 1997

An in-house circular "A question-and-answer about the prevention of injuries that can be caused by turbulence" was issued by the JAL Flight operations Division, the Cabin Attendants Division and the Corporate Safety Division in joint signature.

Responding to a question about a time needed to clear up the things in the cabin in preparation for the ON indication of the seat belt sign, the circular described an answer such as "Although it depends on the situations, it will take about 5 minutes to stow hazardous things in the galley and service carts in the passenger cabin into the appropriate positions."

(11) November 1, 1997 (Revision to "JAL CABIN ATTENDANT MANUAL")

A decision made when the seat-belt sign is switched on was revised as follows, and how to deal with the sign was clarified.

① A seat-belt sign, which is switched on at almost the same time as a 10,000 ft call is made or later than the call, is decided as the sign for landing unless otherwise is instructed.

② A seat-belt sign, which is switched on before a 10,000 ft call is made, is decided as an alert against turbulence.

(12) December 26, 1997

The progress which had been made by the JAL following receiving a Notification No.693 issued by Director-General of Engineering Department of Civil Aviation Bureau of Japan (JCAB) as of September 8, 1997 with respect to reviewing and enhancing the pilot training for autopilot's characteristics of all type of aircraft owned by the company was reported to the Director-General.

(13) January 16, 1998 (Issuance of "OPERATIONS INORMATION MD-11-79)

An in-house notification with respect to characteristics of the MD-11 longitudinal stability on pitch axis.

(14) February 13, 1998 (Issuance of "OPERATIONS INORMATION MD-11-81)

All of the JAL Flight Crew Member were informed by this issuance of how to cope with the over speed (V_{MO}/M_{MO}).

(15) March 4, 1998 (Issuance of "AIRCRAFT OPERATING MANUAL BULLETIN No.75")

Section 4-7 "AUTOMATIC FLIGHT" was partially revised to enhance the contents of WARNING regarding "Never exert a force on the control column/wheel while the AP is engaged" and how to stabilize the aircraft attitude when the aircraft respond abruptly following the AP disconnection.

(16) April, 1998

The training aids of video film was made, regarding the effects of the manual control pressure on the control column to the flight characteristics of the aircraft with the autioilot engaged. This material became use in the periodical pilot training.

(17) April 14, 1998

The progress which had been made by the JAL following receiving a

Notification No.693 issued by Director-General of Engineering Department of Civil Aviation Bureau of Japan (JCAB) as of September 8, 1997 with respect to reviewing and enhancing the pilot training for autopilot's characteristics of all type of aircraft owned by the company was reported to the Director-General.

Additionally, FCOM Temporary Revision 2-827 was not applied to the JAL AOM. The JAL AOM was revised in accordance with FCOM Temporary Revision 2-831 as of June 17, 1998.

Safety Recommendations issued by the NTSB

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: MAY 25 1999

In reply refer to: A-99-39 through -44

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On July 13, 1996, at 2040 eastern daylight time, a McDonnell Douglas[1] MD-11, N1768D, operated by American Airlines as flight 107, experienced an in-flight upset near Westerly, Rhode Island.[2] One passenger received serious injuries, and one passenger and two flight attendants received minor injuries. The airplane was not damaged. Flight 107 was being conducted under the provisions of 14 Code of Federal Regulations (CFR) Part 121 as an international scheduled passenger service flight from London, England, to John F. Kennedy International Airport in Jamaica, New York.

On June 8, 1997, at 1948 Japan standard time, another MD-11, JA8580, operated by Japan Airlines as flight 706, experienced an in-flight upset near Nagoya, Japan. One flight attendant[3] and three passengers received serious injuries, and four flight attendants and five passengers received minor injuries. The airplane was not damaged. Flight 706 was being conducted as a scheduled passenger flight from Hong Kong to Nagoya, Japan. The National Transportation Safety Board is participating in the Japanese Aircraft Accident Investigation Committee's (AAIC) investigation of the accident.

Investigations into these accidents revealed that both upsets occurred when flight crewmembers made manual flight control inputs while the autopilot system was engaged. The accidents raise concerns about the warning information and training provided to MD-11 pilots regarding proper use of the autopilot system that the Federal Aviation Administration should address.

[1] McDonnell Douglas is now known as Boeing, Douglas Products Division (DPD).
[2] For more information, see Brief of Accident NYC96LA148 (enclosed).
[3] The seriously injured flight attendant died from her injuries in February 1999. However, the International Civil Aviation Organization states that an injury must result in death within 30 days of an accident to be classified as fatal.

The MD-11 is equipped with an automatic flight system that includes two flight control computers with integrated autopilots. Each autopilot is capable of automatically controlling the airplane in various vertical and lateral modes. Autopilot controls, located on the flight control panel, include the AUTO FLIGHT switch, which is used to engage the autopilot, and the pitch wheel, which can be used to adjust the airplane's rate of descent. The autopilot can be disconnected by pressing the autopilot disconnect switch on the flight control yoke.

According to Boeing DPD, the MD-11 autopilot cannot respond correctly when manual flight control inputs are made; therefore, pilots should never make control inputs when the autopilot is engaged. If control inputs are made when the autopilot is engaged, there will be a sudden and abrupt movement of some flight control surfaces and an associated but unpredictable aircraft response when the autopilot disengages.

When American Airlines flight 107 was cleared to descend to 24,000 feet, the first officer initiated a descent via the autopilot. With approximately 1,000 feet left in the descent, the captain became concerned that the airplane might not level off at the assigned altitude and instructed the first officer to slow the rate of descent. The first officer adjusted the pitch thumbwheel on the autopilot control panel; however, this maneuver proved ineffective. The captain then took manual control of the airplane, began applying back pressure to the control column, then disconnected the autopilot. Flight data recorder (FDR) data show that the airplane experienced an immediate 2.3 G pitch upset followed by additional oscillations, resulting in the injuries.

Although the Japanese AAIC's final report of the investigation into the Japan Airlines flight 706 in-flight upset has not yet been published, the Safety Board understands that when the airplane was cleared to descend from cruise altitude, the captain initiated a descent via the autopilot. During the descent, the captain stated that he believed the airplane was going to accelerate beyond the maximum operating airspeed. The captain took manual control of the airplane and began applying back pressure to the control column while the autopilot system was still engaged. As the captain's input force increased to about 50 pounds, the autopilot disconnected,[4] and FDR data show that the airplane responded abruptly to the captain's accumulated input force. The airplane experienced a series of pitch oscillations, ranging from +2.78 to -0.5 G, resulting in the injuries.

After the American Airlines upset, the Safety Board researched the information provided to MD-11 pilots about disengaging the autopilot before making manual control inputs. A reference was found in the McDonnell Douglas MD-11 Flight Crew Operating Manual (FCOM) under the heading "Severe Turbulence and/or Heavy Rain Ingestion," which stated

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[4] The autopilot disconnected because of the activation of a feature known as the Autopilot Elevator Command Response Monitor. This monitor will disconnect the autopilot automatically when the position of the elevator differs from the autopilot commanded position. According to Boeing DPD, this can occur when a crewmember applies enough force to the control column to cause the elevator to deflect away from its autopilot commanded position.

> Do not attempt to overpower the autopilot with control forces. This can cause the autopilot to disengage with too much control input, which could result in over control during recovery. Every attempt should be made not to over control.

Safety Board staff questioned Boeing DPD about whether this warning should apply to all flight conditions in which the autopilot may be used, not just conditions of severe turbulence and/or heavy rain ingestion. Following these discussions, the company issued MD-11 FCOM Temporary Revision 2-826, dated December 2, 1997, which contained the following warning in the "Automatic Flight System, General Overview" section:

> Applying force to the control wheel or column while the autopilot is still engaged has resulted in autopilot disconnects and subsequent abrupt aircraft maneuvers. The pilot should never apply force to the control wheel or column while the autopilot is engaged. If the pilot is not satisfied with the autopilot performance, or is unsure that it is operating correctly, it should be immediately disconnected by using one of the autopilot disconnect switches.

The wording of this warning is appropriate; however, the Safety Board is concerned that, because many MD-11 operators use their own company flight manuals (CFM), which may not reflect the information in the McDonnell Douglas MD-11 FCOM, some pilots may not be aware of this warning. Placing the warning in the FAA-approved MD-11 Airplane Flight Manual (AFM), which is required for each airplane delivered, and requiring operators to include the warning in their CFMs will ensure that all pilots are made aware of this safety hazard. Therefore, the Safety Board believes that the FAA should require Boeing to revise the MD-11 AFM and all MD-11 operators to revise their CFMs to ensure that pilots are warned about the hazards of applying force to the control wheel or column while the autopilot is engaged.

Pitch upsets may be more severe in the MD-11 than in other airplanes because the control column forces needed for manual control of the MD-11 in cruise flight can be much lighter than those that pilots might have previously encountered in other airplane models and considerably lighter than those normally used at lower speeds and altitudes.[5] As a result, pilots may overcontrol the MD-11 in manual flight after autopilot disengagement. To minimize this hazard, flight crew training should emphasize the proper procedures for autopilot disconnect and subsequent manual control of the airplane. Therefore, because of the potential for light stick forces in cruise flight, the Safety Board believes that the FAA should issue a flight standards information bulletin that directs principal operations inspectors to ensure that MD-11 training programs provide simulator instruction in the proper procedure for autopilot disengagement and the subsequent manual control of the airplane.

The certification requirements for transport-category autopilot systems are addressed in 14 CFR Part 25.1329, "Automatic Pilot System." Compliance with this regulation is addressed

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[5] National Transportation Safety Board. 1997. *Inadvertent In-Flight Slat Deployment, China Eastern Airlines Flight 583, McDonnell Douglas MD-11, B-2171, 950 Nautical Miles South of Shemya, Alaska, April 6, 1993.* Aircraft Accident Report NTSB/AAR-97-07. Washington, DC.

in Advisory Circular 25.1329-1A, "Automatic Pilot Systems Approval." However, neither of these references includes information about how an airplane should respond when a manual flight control input is made while the autopilot is engaged. The Safety Board is aware that some transport-category airplane autopilot systems are designed to disconnect whenever pilots apply force[4] to the flight controls. A similar design feature would have prevented the pitch upsets that occurred in these two accidents, and the Safety Board is aware that there may be other viable means to prevent such upsets. The Safety Board concludes that the current MD-11 autopilot design, which allows for upsets to occur when pilots apply force to the flight controls, is not acceptable. Therefore, the Safety Board believes that the FAA should require that the MD-11 autopilot system be modified to prevent upsets from occurring when manual inputs to the flight controls are made. In addition, the Safety Board believes that the FAA should review the design of all transport-category airplane autopilot systems and require modifications to those determined to be capable of creating upsets when manual inputs to the flight controls are made. Finally, the FAA should require all new transport-category airplane autopilot systems to be designed to prevent upsets when manual inputs to the flight controls are made.

In the American Airlines flight 107 upset, the first officer adjusted the pitch thumbwheel seven times as the autopilot was attempting to level the airplane after descending. Boeing DPD engineers informed the Safety Board that, when the autopilot is engaged, movement of the pitch thumbwheel interrupts the autopilot's altitude capture mode. Once the pitch thumbwheel is released, there is a 2-second delay before the autopilot can resume the level-off. Therefore, the American Airlines flight crewmember's repeated use of the pitch thumbwheel during the level-off process prevented the autopilot from capturing the assigned altitude. The Safety Board learned that American Airlines operations and training personnel were not aware of this 2-second delay and that it was not addressed in the manufacturer's operations or training material.

After the accident, Boeing DPD issued MD-11 FCOM Temporary Revision 3-101, dated June 18, 1997, which stated the following:

> When the pitch wheel is moved, the AP [autopilot] will cancel the altitude capture mode (if engaged) and will not re-engage in altitude capture until the pitch wheel has come to rest for 2 seconds. Altitude capture will not engage if the pitch wheel is repeatedly adjusted.

Although this information adequately describes the effect of pitch thumbwheel adjustment during altitude capture, the Safety Board is again concerned that, because many MD-11 operators use their own CFMs rather than the McDonnell Douglas MD-11 FCOM, some pilots may not be aware of this warning. Placing the warning in the FAA-approved MD-11 AFM, which is required for each airplane delivered, and requiring operators to include the warning in their CFMs will ensure that all pilots are made aware of this potential safety hazard. Therefore, the Safety Board believes that the FAA should require Boeing to revise the MD-11

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[4] To prevent nuisance disconnects caused by incidental pressure on the controls, the force required to disconnect the autopilot must exceed a threshold value.

AFM and all MD-11 operators to revise their CFMs to ensure that pilots are warned about the hazards of adjusting the pitch thumbwheel during a level off with the autopilot system engaged.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

> Require Boeing to revise the MD-11 Airplane Flight Manual and all MD-11 operators to revise their company flight manuals to ensure that pilots are warned about the hazards of applying force to the control wheel or column while the autopilot is engaged. (A-99-39)
>
> Issue a flight standards information bulletin that directs principal operations inspectors to ensure that MD-11 training programs provide simulator instruction in the proper procedure for autopilot disengagement and the subsequent manual control of the airplane. (A-99-40)
>
> Require that the MD-11 autopilot system be modified to prevent upsets from occurring when manual inputs to the flight controls are made. (A-99-41)
>
> Review the design of all transport-category airplane autopilot systems and require modifications to those determined to be capable of creating upsets when manual inputs to the flight controls are made. (A-99-42)
>
> Require all new transport-category airplane autopilot systems to be designed to prevent upsets when manual inputs to the flight controls are made. (A-99-43)
>
> Require Boeing to revise the MD-11 Airplane Flight Manual and all MD-11 operators to revise their company flight manuals to ensure that pilots are warned about the hazards of adjusting the pitch thumbwheel during a level off with the autopilot system engaged. (A-99-44)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

By: Jim Hall
Chairman

Enclosure

APPENDIX 1 2

FCOM Temporary Revisions (2-767/2-784/2-826)

(1) Temporary Revision 2-767 (As of June 25, 1997)

The following additional text and CAUTION have been added to an item "GENERAL OVERVIEW" of "INTRODUCTION" in AUTOMATIC FLIGHT SYSTEM (AFS).

The autopilot is disconnected by pushing the autopilot disconnect switch located on either the Captain's or the First Officer's outboard yoke handle. This activates the autopilot disengage warning system, which consists of a flashing red boxed AP OFF text and a flashing red box around the flight mode annunciator on the PFD. It also consists of a cyclic aural warning tone and a central aural warning system "AUTOPILOT" optional announcement. If the autopilot disconnect button is held depressed, and the RCWS option is installed, the Roll Control Wheel Steering (RCWS) will be disabled until the button is released.

CAUTION

Do not disengage the autopilot by making manual inputs to the control column and do not apply force on the control column when disconnecting the autopilot. If a force is applied to the control column while disengaging the autopilot, the aircraft will respond abruptly.

(2) Temporary Revision 2-784 (As of August 29, 1997)

This revision replaced temporary Revision 2-767 to revise the CAUTION concerning the AFS and change it to a WARNING as follow.

The autopilot is disconnected by pushing the autopilot disconnect switch located on either the Captain's or the First Officer's outboard yoke handle. This activates the autopilot disengage warning system, which consists of a flashing red boxed AP OFF text and a flashing red box around the flight mode annunciator on the PFD. It also consists of a cyclic aural warning tone and a central aural warning system "AUTOPILOT" optional announcement. If the autopilot disconnect button is held depressed, and the RCWS option is installed, the Roll Control Wheel Steering (RCWS) will be disabled until the button is released.

WARNING

Unless the autopilot is malfunctioning, the pilot should not over power or assist the autopilot with control column or control wheel forces. This can cause the autopilot to disengage with too much control input, which could result in over control during recovery. If a force is applied to the control column or control wheel while disengaging the autopilot, the aircraft will respond abruptly.

(3) Temporary Revision 2-826 (As of December 2, 1997)

This revision replaced temporary Revision 2-784 to revise the WARNING for adding the following descriptions.

This revision also included a revision concerning a item "APPROACH" but is omitted here.

In addition, a temporary revision 2-827 (December 2, 1997) reflected this revision in an item "SEVERE TURBULENCE AND/OR HEAVY RAIN INGESTION"

The autopilot is disconnected by pushing the autopilot disconnect switch located on either the Captain's or the First Officer's outboard yoke handle. This activates the autopilot disengage warning system, which consists of a flashing red AP OFF text and a flashing red box around the flight mode annunciator on the PFD. It also consists of a cyclic aural warning tone and a central aural warning system "AUTOPILOT" optional announcement. If the autopilot disconnect button is held depressed, and the RCWS option is installed, the Roll Control Wheel Steering (RCWS) will be disabled until the button is released.

The pilot is responsible for monitoring the autopilot whenever it is engaged. If the pilot is not satisfied with the autopilot performance, or is unsure that it is operating correctly, it should be immediately disconnected by using one of the autopilot disconnect switches. The pilot should smoothly stabilize the aircraft attitude, retrim if necessary and reengage the autopilot if desired.

NOTE

Because the autopilot cannot respond correctly when inputs are made to the control wheel or column, it is designed to disconnect automatically if there are sustained pilot inputs. However, the pilot should never make control inputs when the autopilot is engaged, because at disconnect there will be a sudden and abrupt movement of some flight control surfaces with an associated but unpredictable aircraft response.

WARNING

Applying force to the control wheel or column while the autopilot is still engaged has resulted in autopilot disconnects and subsequent abrupt aircraft maneuvers. Pilots have over-controlled the aircraft while trying to return to stabilized level flight. The pilot should never apply force to the control wheel or column while the autopilot is engaged. If the pilot is not satisfied with the autopilot performance, or is unsure that it is operating correctly, it should be immediately disconnected by using one of the autopilot disconnect switches. If the autopilot disengages while a force is applied to the control wheel or column, there will be a rapid, commanded change in some of the control surface positions. This will result in an abrupt and unpredictable aircraft response. Additionally, the pilot should not attempt to disconnect the autopilot while applying a control force. If an inadvertent autopilot disconnect occurs, the pilot must smoothly stabilize the aircraft attitude, releasing the flight controls, if necessary, until the aircraft motion dampens out.

Excerpts from Documents related to
Maximum Operating Limit Speed

The followings are excerpts from the related documents in which the definitions of Maximum Operating Limit Speed are described.

1. Descriptions in Airworthiness Requirements

The Federal Aviation Regulations (FAR) §25.1505 defines the maximum operating speed limit as follow.

> **§ 25.1505 Maximum operating limit speed.**
>
> The maximum operating limit speed (V_{MO}/M_{MO} airspeed or Mach Number, whichever is critical at a particular altitude) is a speed that may not be deliberately exceeded in any regime of flight (climb, cruise, or descent), unless a higher speed is authorized for flight test or pilot training operations. V_{MO}/M_{MO} must be established so that it is not greater than the design cruising speed V_C and so that it is sufficiently below V_D/M_D or V_{DF}/M_{DF}, to make it highly improbable that the latter speeds will be inadvertently exceeded in operations. The speed margin between V_{MO}/M_{MO} and V_D/M_D or $V_{DF}M/_{DF}$ may not be less than that determined under § 25.335(b) or found necessary during the flight tests conducted under § 25.253.
>
> [Amdt. 25-23, 35 FR 5680, Apr. 8, 1970]

Abbreviations;

"V_C" means design cruising speed. "V_D/M_D" means design diving speed.

"V_{DF}/M_{DF}" means demonstrated flight diving speed.

"Design Dive Speed" is determined under §25.335(b) and "High-Speed Characteristics" is determined under §25.253, but contents of those are omitted here. Further, equivalent descriptions with respect to the maximum operating limit speed are found in "Airworthiness Requirements" in Japan, but contents of those are also omitted here.

2. Descriptions in Flight Manual and JAL AOM

The previous "Airplane Flight Manual" issued by McDonnell Douglas at the time of the accident contained the following descriptions with the title "Maximum Operating Speed" in item "2. STRUCTUAL DESIGHN" in section "SECTION 1 LIMITATIONS".

Maximum Operating Speeds

The Maximum Operating limit Speed V_{MO}/M_{MO} may not be deliberately exceeded in any regime of flight.(climb,cruise,or descent) (Later parts are omitted.)

The JAL AOM also contained descriptions equivalent to the above.

3. Descriptions in the FCOM and the JAL AOM

The previous FCOM issued by McDonnell Douglas at the time of the accident contained the following descriptions with the title "Maximum Operating Speed" in item 2 "STRUCTUAL DESIGHN" in section 1 "LIMITATIONS" of VOL Ⅱ "Operating Procedures".

Maximum Operating Speeds

The maximum operating speed V_{MO}/M_{MO} may not be deliberately exceeded in any regime of flight (climb, cruise, or descent).

(Later Parts are omitted.)

The JAL AOM described "Maximum Operating Limit Speed (V_{MO}/M_{MO}) in item 1 "Airspeed Limitation" in section 1-2-2 "Airspeed and Load Factor" of volume "Aircraft Limitation".

Although the JAL AOM was based on the FCOM in principle, the first sentence of the FCOM description "The maximum...........or descent" was ommitted in the AOM at the time of the accident and subsequently added to it.

4. Description in the JAL maintenance manual regarding a maintenance at the time of the occurrence of the overspeed

If a MD-11 exceeded the V_{MO}/M_{MO} (an overspeed-clean wing condition), the aircraft is required to undergo an inspection per the "MD-11 Aircraft Maintenance Manual". The following are inspection items in the manual.

If the overspeed is no more than 10 knots above the maximum operating speed (Vmo/Mmo),inspect external fuselage per paragraph 4.A.(1). Do not remove the fillet panels,inspect external fuselage skin only. If the overspeed is more than 10 knots above the maximum operation speed(Vmo/Mmo),do all the inspection per paragraph 4.A.(1) through 4.A.(7). If there is too much turbulence/buffeting during the overspeed,do all the inspection per paragraph 4.A.(1)through 4.A.(7).

APPENDIX 14

The Time Difference between CWS-PITCH and CCP recorded on the ADAS

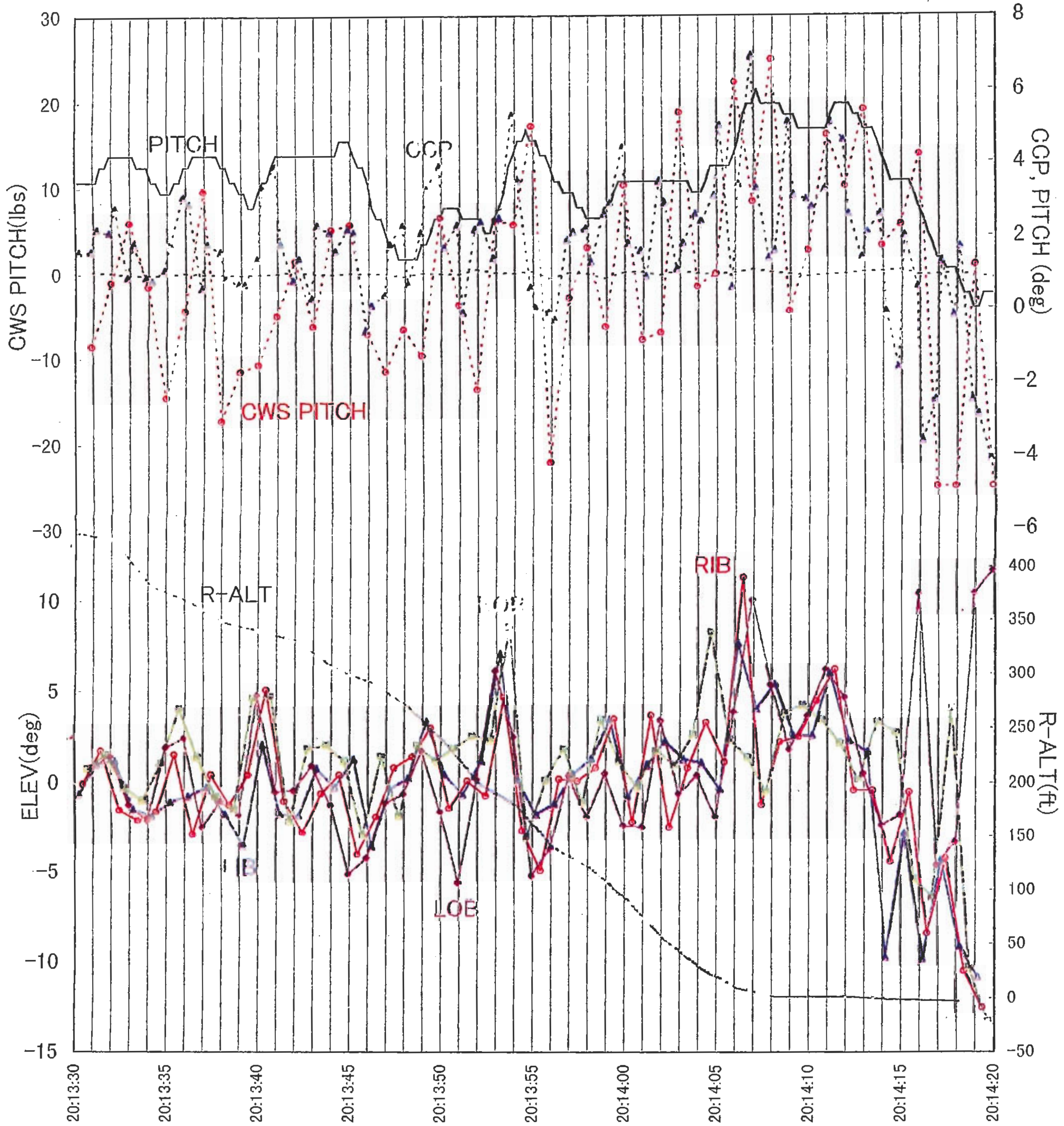
As mentioned in Section 2.8.2 "DFDR and ADAS Recordings" in the main body of this report, the major parameters attached as Appendix 1 were plotted as a function of time which was actually recorded on each word slot on the subframe (one second) of the DFDR and ADAS without considering each parameter's time delay on a data bus from the sensor to the time when the data is recorded on the DFDR or ADAS. The ADAS's recording medium consists of 512 words per second (subframe). The CWS-PITCHs (CAP1A and CAP1B) of the MD-11 were recorded on the 503 and 504 word slot of the subframe, respectively, and the CCP was recorded twice per second on the 14 and 446 word slot of the subframe. Due to this, the movement of Control Column Force (CWS-PITCHs) appears to lag behind that of Control Column Position (CCP) on the attached graph (Appendix 1-2).

Although, taking into consideration a time delay on the data bus, parameters are theoretically sampled at the sensors at an earlier time than the time when the parameters are actually recorded on the ADAS, it is impossible to identify which parameter (e.g. CWS-PITCH or CCP) comes first to the ADAS because the time delay of each parameter on the data bus can vary zero to some seconds.

Accordingly, in order to determine whether the time difference between the CWS-PITCHs and the CCP on the ADAS shown in Appendix 1-2 was attributed to an erroneous event at the time of the accident or usually occurs associated with a recording system of the ADAS, parameters (Pitch, CWS-PITCHs, CCP and Elevators) of the MD-11 during uneventful flight after the accident from final approach to landing at Nagoya airport were plotted by the same way as Appendix 1-2. The plotted data are shown in Figure A14.

It is apparent from Figure A14, showing that the timing relationship among the parameters is equivalent to that shown in Appendix 1-2, that the time difference between the CWS-PITCHs and the CCP is associated with the recording characteristics of the ADAS including the time delay on the data bus. Thus, it is estimated from a standpoint of mechanism of the control column that the movement of Control Column Force (CWS-PITCH) and Control Column Position (CCP) simultaneously occurred.

Figure A14 The Timing Relationship between CWS-PITCH and CCP while the Aircraft was in Final Approach to Nagoya Airport



APPENDIX 15

Supplemental Explanation of the Autopilot Disengagement

1. Conditions of Autpilot Disengagement

   The JAL AOM defines conditions of AP disengagement as follows;

   FCC will disengage autopilot at the following conditions.

   (1) Vertical "G" is more than $1\pm0.6\sim1\pm1.4$ (Effects the pitch rate at the time).

   (2) Roll rate is more than 10 deg/sec.

   (3) Bank angle is more than 60°

   (4) Position of each control surface differs from that commanded by the autopilot due to Pilot's override control etc.

   Note 1: (1)～(3) will activate Automatic Cut-Off (ACO) of the autopilot.

   Note 2: (4) will activate ECRM.

2. Reasons that the ACO was not contributing factor to the AP disengagement in this accident.

   As mentioned in the main body of this accident report, the AP disengagement at the time of the accident was estimated to have been caused by the FCC ECRM activation. The following are the reasons that the above items (1)～(3) were not contributing factors to the AP disengagement in this accident.

   ① An analysis of the above item 1-(1) "Vertical G"

   In the case that the vertical acceleration(G) is increasing in the upward direction, the ACO will be activated when the vertical G exceeds the 1+0.6G to 1+1.4G range.

   When this condition causes the ACO to be activated, a fault message "AP P ACO" is recorded in the CFDS (Centralized Fault Display System). However, there was no evidence of such recording at the time of the accident.

   Values of the vertical G detected by the IRU are used to activate the ACO. The FCC ACO logic has a time lag of one second from the actual time when the vertical G was detected by the IRU until the time when the FCC outputs a signal to activate the ACO.

   Further, according to information provided by the manufacturer, there is a time delay up to one second in the AP's ON/OFF data on a data bus from the sensor to the time when the data is recorded on the DFDR.

   Because of these time delays, a value of the vertical G detected by the IRU would not have reached +1.6G one second ahead of an actual time when the AP was disconnected.

   ② When the above item 1-(2) "Roll Rate" causes the ACO to activate, a fault message "AP R RATE ACO" is recorded in the CFDS. However, there was no evidence of such recording at the time of the accident.

In addition, the DFDR recorded small values of the roll angle (about 0° with less than 10° /sec of roll rate) shortly before the AP disengagement.

③ When the above item 1-(3) "Bank Angle" causes the ACO to activate, a fault message "AP R ACO" is recorded in the CFDS. However, there was no evidence of such recording at the time of the accident.

In addition, the DFDR did not record a bank angle in excess of 60° shortly before the AP disengagement.

8 COMMENTS FROM THE UNITED STATES OF AMERICA

(NOTE)

Because of the editorial reason, each page number of the Final Report does not always corresponds to that of the Draft Final Report.

National Transportation Safety Board

Washington, D.C. 20594

November 17, 1999

Mr. Atsuhiko Wataki
Investigator-in-Charge, JAL 706
Aircraft Accident Investigation Commission
Ministry of Transport
Tokyo, Japan

BY FACSIMILE

Dear Mr. Wataki,

Thank you for the opportunity to comment on the draft report of the accident, JAL flight 706 of June 8, 1997, an MD-11 airplane, JA8580, near Nagoya, Japan. The National Transportation Safety Board (NTSB) staff participated in the investigation as the state of manufacture of the MD-11 aircraft in accordance with Annex 13 to the ICAO Convention with advisors from the Federal Aviation Administration (FAA) and the Boeing Commercial Airplane Group (formerly McDonnell Douglas Aircraft). We believe our participation has been beneficial to all.

We wish to congratulate the JAAIC for the depth and focus of the investigation. The draft Final Report is an excellent example of professionalism.

We have only a few points of comment, however, we believe they are sufficiently important that adjustment in the text would be appropriate.

Para. 2.11.1 Subparagraph (2), MD-11 Autopilot System, draft page 25, contains a sentence that reads, According to Mc Donnell Douglas, the sole reason for the autopilot override function,... The sentence would be more correct with the following modification, "the reasons for the autopilot override function on the MD-11 are to provide pilots with a backup disconnect function in the case of an autopilot hardover or where pilots find that they are not able to disconnect the auto pilot using the disconnect button."

Para. 2.11.1 Subparagraph (2), MD-11 Autopilot System 2, draft page 26, contains a sentence that reads, "This function has an Overspeed Protection logic such that..." It would be more correct with the following modification, "This function has an speed limiting logic such that..."

Para. 2.11.3 Subparagraph (2), end sentence, draft report page 29. The sentence would offer more clarity with the following modification, "The engineering flight simulator demonstrations at Mc Donnell.......activate the ECRM and produce the G forces recorded on the FDR."

Para. 3.2.2. draft report page 33. In the paragraph which begins, "At 1948:21, the speed brakes (Spoilers) began to deploy...." The last sentence of the paragraph would be more correct if the current words, the AP's "speed protection function" were replaced with the words, "speed limiting logic."

Para. 3.3.1, subparagraph (2) draft report page 35. The title of the paragraph and the first sentence refer to the speed protection function. This subject should be called the speed limiting logic.

Para. 3.3.1, subparagraph (2) draft report page 36. The first sentence on the page begins, "Thus, it is estimated that the FCC airspeed had not reached...." It is appropriate to further explain the operation of the FCC airspeed filter by inserting the following information before this sentence: "The time lag becomes a factor in airspeed filter convergence when the wind rates exceed 1.1 knots per second."

Para. 3.3.1, subparagraph (3) draft report page 36. The paragraph that reads, "The effectiveness of the speed brakes for decreasing the airspeed..." needs modification to fully describe the airplane performance in the FLC mode. A suggested insert follows:

> In the FLC mode with the autopilot engaged, speed is controlled by airplane pitch attitude changes, referred to as "speed on pitch." Speed brake deployment in the FLC mode will not slow the airplane speed, rather, deployment results in an increased rate of descent to maintain the target airspeed. Therefore, in the FLC mode, when the speedbrakes are deployed, the autopilot will not attempt to slow the airplane; it will command a nose down elevator to maintain speed.
>
> In analyzing the elevator position data during speedbrake deployment, there are two reasons for the commanded nose down elevator. The autopilot inner loop will attempt to counter the normal nose up pitching moment due to the aerodynamic changes in the wing and changes in the downwash on the tail. Secondly, the autopilot outer loop will command a nose down elevator to maintain speed. During the timeframe of speedbrake extension, data indicates that the filtered FCC-airspeed did not keep up with the actual CAS in the decreasing tail wind condition which resulted in a speed excursion.

Also, the word "fully" in the next paragraph, last sentence, should be dropped.

Para. 3.3.1, subparagraph (3) draft report page 37. The paragraph that reads, "Assuming that the Captain adequately adjusted the V/S wheel..." tends toward speculation rather than the engineering facts associated with FCC design logic for engaging the V/S mode. Lacking factual explanation, it is appropriate to delete this paragraph. Note then, the related safety recommendation regarding a design review of the AP system in FLC to changeover to V/S mode is not supported and should be deleted.

Para.4, CAUSES, subparagraph (1), draft report page 45. The sentence that reads, "Thus, the AP system (FCC-airspeed) had a time lag in converging the airspeed on the selected target airspeed." should have the following words added for clarity, "...with wind rates in excess of 1.1 knots per second.

Para.4, CAUSES, draft report page 45, last item which reads "(2) A lack of pilot education and training by using the simulator." It would be beneficial to continue the sentence as follows, "...regarding inappropriate AP disconnect and control of pitch oscillations using excess pitch control forces."

Para. 6, Safety Recommendations. With reference to ICAO Annex 13, para. 7.5, Safety Recommendations, Dispatch, if you wish, please feel free to address the JAAIC recommendations to the U.S. National Transportation Safety Board. Both the NTSB and the FAA have extensive recommendation tracking systems.

As a general note, FAA participants suggested that I convey to you, for clarity, that the manufacturer's FCOM is accepted - but not approved - by the FAA. The only manual approved by the FAA is the AFM (Airplane Flight Manual). It is expected that state civil regulatory authorities will exercise oversight over their airline's operating manuals, using the manufacturer's FCOM as a guide, but perhaps requiring airlines to develop company specific operating manuals.

Again, please allow me to thank the JAAIC for the in-depth, participative way in which you and your staff have conducted the investigation. Your promotion of fastening seat belts at all times is very commendable. Your total efforts have made a major contribution to aviation safety in the future.

With best regards,

Robert M. MacIntosh
U.S. Accredited Representative, JAL 706