AA2006-1

AIRCRAFT ACCIDENT INVESTIGATION REPORT

JAPAN AIRLINES FLIGHT 356
BOEING 747-400D, JA8903
OVER THE SEA 8 NM S.E. OF HAMAMATSU CITY, JAPAN
OCTOBER 21, 2002

January 27, 2006

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

The investigation for this report was conducted by Aircraft and Railway Accidents Investigation Commission, ARAIC, about the aircraft accident of Japan Airlines Flight 356 Boeing 747-400D in accordance with Aircraft and Railway Accidents Investigation Commission Establishment Law and Annex 13 to the Convention of International Civil Aviation for the purpose of determining cause of the aircraft accident and contributing to the prevention of accidents and not for the purpose of blaming responsibility of the accident.

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

Junzo Sato,
Chairman,
Aircraft and Railway Accidents Investigation Commission

Abbreviations

Abbreviated words used in this report are as follows:

ACARS	: Aircraft Communications Addressing and Reporting System
ACMS	: Aircraft Condition Monitoring System
ADC	: Air Data Computer
AFDS	: Autopilot Flight Director System
AFM	: Airplane Flight Manual
ALT	: Altitude
AOA	: Angle Of Attack
AOM	: Aircraft Operating Manual
APC	: Aircraft Pilot Coupling
A/P	: Autopilot
A/T	: Autothrottle
ATC	: Air Traffic Control
CA	: Cabin Attendant
CAPPI	: Constant Altitude Plan Position Indicator
CAT	: Clear Air Turbulence
CAS	: Computed Air Speed
CCP	: Control Column Position
CDU	: Control Display Unit
CVR	: Cockpit Voice Recorder
DFDR	: Digital Flight Data Recorder
DME	: Distance Measuring Equipment
ECON	: Economy
EICAS	: Engine Indication and Crew Alerting System
FAA	: Federal Aviation Administration
FCC	: Flight Control Computer
FCS	: Flight Control System
FD	: Flight Director
FL	: Flight Level
FLCH	: Flight Level Change
FMC	: Flight Management Computer
FMS	: Flight Management System

IAS	:	Indicated Air Speed
ICAO	:	International Civil Aviation Organization
IRU	:	Inertial Reference Unit
JST	:	Japan Standard Time
KIAS	:	Knots Indicated Air Speed
LNAV	:	Lateral Navigation
MAC	:	Mode Control Panel
MMO	:	Maximum Operating Limit Speed
ｎｍ	:	Nautical Mile
N 1	:	Low Pressure Rotor Speed
OM	:	Operations Manual
PA	:	Passenger Address
PCP	:	Power Control Package
PF	:	Pilot Flying
PFD	:	Primary Flight Display
PIC	:	Pilot In Command
PIO	:	Pilot Involved Oscillation, or Pilot Induced Oscillation
PNF	:	Pilot Not Flying
PTH	:	Path
PVS	:	Pilot-Vehicle System
QNH	:	Pressure Setting to Indicate Elevation above Mean Sea Level
RNAV	:	Area Navigation
SAT	:	Static Air Temperature
SPD	:	Speed
TAS	:	True Air Speed
TCAS	:	Traffic Alert and Collision Avoidance System
TOD	:	Top Of Descent
TURB	:	Turbulence
UTC	:	Universal Time Coordinated
VNAV	:	Vertical Navigation
VOR	:	VHF Omni-directional Radio Range
VORTAC	:	VHF Omni-directional Radio Range Tactical Air Navigation
VMO	:	Maximum Operating Limit Speed
V/S	:	Vertical Speed

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AIRCRAFT ACCIDENT INVESTIGATION REPORT

JAPAN AIRLINES FLIGHT 356
BOEING 747-400D, JA8903
SERIOUS INJURIES DUE TO TURBULENCE
OVER THE SEA 8 NM S.E. OF HAMAMATSU CITY, JAPAN
AT ABOUT 10:57 JST, OCTOBER 21, 2002

December 21, 2005

Decision by the Aircraft Accidents investigation Commission (Air Sub-Committee Meeting)

Chairman	Junzo Sato
Member	Yukio Kusuki
Member	Susumu Kato
Member	Sumio Matsuura
Member	Yukiko Kakimoto
Member	Akiko Matsuo

1 PROCESS AND PROGRESS OF THE ACCIDENT INVESTIGATION

1.1 Summary of the Accident

On Monday October 21, 2002, a Japan Airlines (JAL) Boeing 747-400D, registration JA8903, departed Fukuoka Airport as scheduled passenger flight 356. While descending from cruising altitude for Tokyo International Airport at 10:57 (JST) over the sea approximately 8nm southeast of Hamamatsu City at an altitude of around 39,000ft, the aircraft was shaken abruptly and_at that time three passengers and a member of the cabin crew were seriously injured, and 18 passengers and 11 cabin crew sustained minor injuries.

There were 556 persons on board flight 356 — 541 passengers (including three infants), the captain and 14 other crewmembers. The interior of the cabin was partly damaged when the aircraft was shaken abruptly.

1.2 Outline of the Accident Investigation

1.2.1 The Organization of the Investigation

(1) On October 21, 2002, the Aircraft and Railway Accidents Investigation Commission (ARAIC) assigned an Investigator-in-Charge and three other investigators to investigate the accident.

(2) On January 15, 2003, three technical specialists were assigned to investigate the following specialized items.

① Investigation of aircraft motion

Flight Experiment Group, Flight System Research Center, National Aerospace Laboratory
Team leader — Mr. Kazuya Masui

Flight Experiment Group, Flight System Research Center, National Aerospace Laboratory
Helicopter Flight Safety Team — Mr. Naoki Matayoshi

② Investigation of weather

Japan Aircraft Pilot Association
Consultant — Doctor Akira Nakayama

1.2.2 Cooperation by Foreign Authorities

An Accredited representatives and technical advisors from the United States of

America, the state of design and manufacture of the aircraft, participated in the investigation.

1.2.3 The Implementation of the Investigation

The investigation proceeded as follows.

October 21-22, 2002	Investigation of the aircraft and collection of witness statements.
February 20, 2004	Simulated flight tests using flight simulator

1.2.4 Progress Report

On September 26, 2004, the ARAIC submitted a progress report on the results of the factual investigation at that time to the Minister of Land, Infrastructure and Transport, and this was opened to the public.

1.2.5 Hearings from Persons relevant to the Cause of the Accident

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

1.2.6 Comments from States participating in the investigation

Comments on this report were invited from the state participating in the investigation.

2 FACTUAL INFORMATION

2.1 History of the Flight

On October 21, 2002, a Boeing 747-400D of Japan Airlines (JAL: 'the company'), registration JA8903, took off from Fukuoka Airport at 19:28 (JST) as Japan Airlines scheduled flight 356 to Tokyo International Airport with 556 persons on board — 541 passengers (including three infants), the captain and 14 other crewmembers.

In the cockpit, the captain acting as Pilot Not Flying (PNF: the pilot assuming duties other than controlling the aircraft) occupied the left seat, a first officer undergoing line training (Note 1) acting as Pilot Flying (PF: the pilot controlling the aircraft) occupied the right seat, and the assigned first officer was sitting on the observer's seat.

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

> FLIGHT RULES: IFR, DEPARTURE AERODROME: Fukuoka Airport, TIME: 10:00, CRUISE SPEED: 488kt, CRUISE ALTITUDE: FL410 (Note 2), ROUTE: TAE (OITA VOR/DME) – Y23 (RNAV ROUTE) – VIOLA (REPORTING POINT) – Y21 (RNAV ROUTE) – XAC (OSHIMA VORTAC) – V17 (AIRWAY) – WESTIN (REPORTING POINT), DESTINATION AERODROME: Tokyo International Airport, TOTAL EET: 1 hours 07minutes, ALTN AERODROME: Nagoya Airport ENDURANCE: 3 hours 19 minutes.
>
> (Note 1): See section 2.12.5.
>
> (Note 2): "FL" (flight level) is altitude expressed as the value of the altimeter indication divided by 100 when the altimeter pressure setting is set to 29.92inHg. A cruising altitude of FL370 was originally filed, but was changed to FL410 before the aircraft departed Fukuoka Airport.

2.1.1 History of the Flight based on Digital Flight Data Recorder, Cockpit Voice Recorder and ATC Radio Communication Recordings

The subsequent history of the flight based on data recorded on the aircraft's Digital Flight Data Recorder (DFDR) data, Aircraft Condition Monitoring System (ACMS) and Cockpit Voice Recorder (CVR), and on ATC radio communication recordings, is summarized as follows:

At around 10:35, the aircraft reached its cruising altitude of FL410.

At around 10:52, while the aircraft was cruising at FL410, Tokyo Air Control

Center (Tokyo Control) instructed the aircraft to change ATC radio communication frequency to 123.7MHz, and the aircraft complied.

At around 10:55, the aircraft contacted Tokyo Control and requested to descend. Tokyo Control responded, “JAL356, roger, descend and maintain flight level 160, cross SPENS at flight level 160”.

At 1056:35, the aircraft started to descend from FL410 at the top of descent (TOD, the starting point of the descent) calculated by its Flight Management Computer (FMC) (Note 3) with the autopilot engaged in VNAV/PTH mode (Note 4).

At 1057:18, the N1 (engine low-pressure spool speed) values of all four engines reduced to around idle. The aircraft was descending at an altitude of 39,885ft at a speed of Mach 0.864.

At 1057:19, the aircraft’s speed reached Mach 0.871, and began to increase slowly.

At 1057:26, the aircraft’s speed reached Mach 0.886.

At 1057:27, the aircraft’s speed decreased to Mach 0.879.

At 1057:28, the aircraft’s speed increased to Mach 0.881, and the captain called “Speed, speed”.

At 1057:29, the autopilot pitch mode changed from VNAV/PTH to VNAV/SPD (Note 4) at an altitude of 39,450ft. The speed at this time was Mach 0.866.

At 1057:30, the aircraft’s speed was Mach 0.865.

At 1057:31, the aircraft’s speed was Mach 0.859.

At 1057:32, a speed value of Mach 0.865 was selected on the autopilot Mode Control Panel (MCP).

At 1057:33, the aircraft’s speed was Mach 0.867. The captain called “Make an intervention (Note 6) to bring it back more.”

At 1057:34, the aircraft’s speed was Mach 0.865.

At 1057:35, the aircraft’s speed was Mach 0.869.

At 1057:36, a speed value of Mach 0.80 was selected on the MCP. The aircraft’s speed was Mach 0.876.

At 1057:37, the aircraft’s speed was Mach 0.867.

At 1057:38, the aircraft's speed was Mach 0.914. At this time, the Control Column Position (CCP) moved from nose down to slightly nose up of +0.5°(a positive CCP value indicates nose up), aircraft pitch angle was –0.4°, AOA was –12.1° (Note 7) and vertical acceleration became +1.14G (vertical acceleration is positive upwards). The ACMS Inertial Reference Unit (IRU) output was +1.16G.

At 1057:39, the aircraft's speed was Mach 0.889, CCP increased further nose up, the aircraft's pitch angle became 0°, AOA was –12.3° and vertical acceleration was +1.24G. (The IRU output was +1.33G.)

At 1057:40, the aircraft's speed reached Mach 0.903, and CCP at this time was +4.6. Pitch angle became further nose up of +2.5° and AOA was –9.8°, vertical acceleration was around +1.89G. (The IRU output was +1.88G.)

At 1057:41, the stick shaker operated while the aircraft was descending through 39,040ft at Mach 0.884. The CCP began to move toward nose down of –1.4°, pitch angle was +6.4°, AOA was –5.4°, vertical acceleration was +1.95G (IRU output was +1.88G).

At 1057:42, the autopilot disengaged. The stick shaker was operating while the aircraft was flying at 38,940ft at Mach 0.871. The CCP moved significantly nose down (–9.6°), pitch angle was +8.3°, AOA was –7.9°, vertical acceleration was +1.86G.

At 1057:43, the captain called "I have control" and the first officer replied, "You have control". The aircraft's speed was Mach 0.859, CCP was nose down at –12.5°, pitch angle was +5.2°, AOA was –17.2°, and vertical acceleration was –0.39G.

At 1057:44, the aircraft's speed was Mach 0.854, CCP was +2.3°, pitch angle was –1.5°, AOA was –19.5°, and vertical acceleration was –0.34G.

At 1057:45, the aircraft's speed was Mach 0.853, CCP was +4.0°, pitch angle was +0.8°, AOA was –13.5°, and vertical acceleration was +1.72G. A small metallic clashing sound was recorded on the CVR.

AT 1057:46, the aircraft's speed was Mach 0.847, CCP was –3.3°, pitch angle was +6.1°, AOA was –6.1°, and vertical acceleration was +1.77G.

At 1057:47, the captain called "Seatbelt on", and the stick shaker operated again.

The aircraft's speed was Mach 0.847, CCP was –4.9°, pitch angle was +6.2°, AOA was –11.4°, and vertical acceleration was +1.48G.

At 1057:48, the aircraft's speed was Mach 0.842, CCP was –3.7°, pitch angle was +2.6°, AOA was –15.8°, and vertical acceleration was +0.66G.

At 1057:50, the captain called "Ignition on". The aircraft's speed was Mach.831, CCP was +1.5°, pitch angle was +2.8°, AOA was –11.3°, and vertical acceleration was +1.34G.

At 1057:52, vertical acceleration attained +0.79G, and after this there were no further large variations in pitch and vertical acceleration.

At 1058:03, a cabin announcement "Ladies and gentlemen, please fasten your seatbelt tight and low" was made.

At 1059:28, the autopilot was reengaged.

At 1059:35, a cabin attendant (CA) made the first report on passenger injuries to the captain. After this, there were several further cabin situation reports from CAs and directions, etc. from the captain in reply to those.

At 1104:59, the captain reported to Japan Airlines radio station at Haneda (company radio) that some passengers had been injured while encountering TB4 turbulence (Note 8) but that he did not yet know the state of their injuries, and that he would report later if it were necessary to arrange for ambulances etc.

At 1106:10, Tokyo Control instructed the aircraft to contact Tokyo Approach Control. The aircraft received radar vectors from Tokyo Approach Control and began its approach to Tokyo International Airport.

At 11:23, the aircraft landed Tokyo International Airport.

The accident occurred when significant vertical acceleration (G) was recorded at around 10:57 an altitude of around 39,000ft over the sea around 8nm southeast of Hamamatsu city.

(Note 3): "FMC" is the central Flight Management System computer that automatically computes flight management (navigation, maneuver, thrust adjust, guidance, etc.) over the entire flight from take-off to landing.

(Note 4): "VNAV/PTH" and "VNAV/SPD" are sub-modes of the autopilot VNAV (vertical navigation) pitch mode.

In VNAV/PTH mode, the autopilot controls the aircraft's pitch to maintain the FMC target altitude or VNAV/PATH. The Autothrottle (A/T) operates in speed mode.

In VNAV/SPD mode, the autopilot controls the aircraft's pitch to maintain a target speed. The A/T operation mode varies depending on the flight phase, including THR REF (thrust mode selected by the FMS), THR (thrust varied to maintain the rate of climb or descent required by the active pitch mode), IDLE, etc.

(Note 5): The MCP is a panel located on the glare shield that houses the control switches and displays for pilots to select and control the engaged flight director, autopilot and FMC Autothrottle modes.

(Note 6): "Intervention" is short for "speed intervention" and means that pilot temporarily controls the flight speed maintained by the autopilot using the MCP. See section 2.11.5 (6).

(Note 7): The numerical value of AOA is the data calculated by ADC, and is not the value measured by AOA vane.

(Note 8): "TB4" is a technical term used for expressing the strength of turbulence in company radio and ACARS reports, and is specified in the "Company Turbulence Reporting Standards" in the Japan Airlines' Operations Manual Supplement. It corresponds to "moderate" in ICAO/FAA standards. Turbulence strength can range from TB0 (smooth) to TB7 (extreme).

(See Figures 1, 3-1, 3-2, 3-3, 3-4 and Photos 1, 2 and 3.)

2.1.2 Statements of the flight crew relating to the flight history

(1) The Captain

"There was a flight crew complement of three on the day of the accident; a recently-promoted first officer undergoing line training for PF duties ('first officer') in the right seat, the assigned first officer and myself. It was planned that the first officer would assume PF duties from take-off to landing on flights 353 and 356 of the round trip from Haneda to Fukuoka.

"I showed up at 6:00, and received the dispatch briefing as usual. I confirmed the weather conditions by AMEDAS, etc. There was widespread cloud with scattered echoes, and I expected that there might be light turbulence in flight through cloud.

“I made the first officer under training select the flight altitude. I also made him brief the cabin attendants.

“While flying to Fukuoka, we received an ACARS report over of TB4 turbulence at 35,000ft near Kushimoto, but I didn’t think this directly concerned flight 353 to Fukuoka.

“After we arrived at Fukuoka, considering the turbulence information received during flight 353, I changed the altitude for the return flight 356 from the originally filed FL370 to FL410.

“On flight 356 from Fukuoka to Haneda, the first officer was flying the aircraft from the right seat and took off from Fukuoka. On the way to MIKNI point, we received ATC clearance “Direct FLUTE” [fly directly to FLUTE] and we flew smoothly at 41,000ft. The center autopilot was engaged in VNAV/PTH mode.

“There was absolutely no cloud at 41,000ft, and no turbulence. After that, we were flying ‘on top’ over stratus-type cloud.

“When we were almost over FLUTE, Tokyo Control directed us ‘Present position direct Oshima’. Flying over FLUTE, we began to descend in VNAV/PTH mode and ECON speed (Note 9).

“At the start of the descent, there was nothing that could be considered as an echo on the weather radar, so I didn’t switch on the seatbelt signs. Further, when the speed began to increase and we were encountering rattling vibrations, I did not switch on the seatbelt signs because dealing with those things took priority.

“After starting the descent, rattling vibrations started from around 39,000ft. The trend indication (Note 10) on the airspeed indicator showed speed increasing, so the first officer operated speed intervention. Our speed was Mach 0.86 when he pushed the switch. Therefore, although I had set the command speed to Mach 0.80, the trend indicator further showed a speed increase tendency.

“I don’t quite remember what order events happened in after that, but I pulled the speed brakes, and then called ‘I have’. After that, I felt a tendency to pitch up. After that the stick shaker operated, and so I pitched down and felt negative G sensations such as my body floating up as I did so.

“I don’t remember whether I disconnected the autopilot or whether it disengaged automatically. It was off when I confirmed that I was in control of the aircraft. Then, I turned on the seatbelt signs and made a PA (Passenger Address System) to fasten seatbelts.

“I don’t know whether we were in cloud during the turbulence, but there was nothing that could be considered as an echo on the weather radar.

“During the flight before encountering the turbulence, there was an ACARS report of TB4 turbulence at 37,000ft over FLUTE. However, I didn’t think there would be turbulence since we were flying at 41,000ft at the time and there was absolutely no vibration at that altitude, and looking at the cloud situation there was nothing that looked like a convective cloud. Also, that was only that single report relating to turbulence, even though there should have been many other company scheduled flights operating at that time.”

(2) The First Officer

“On the day of the accident, the briefing for the whole one day was conducted from 06:00 between the captain, the assigned first officer, the dispatcher and me. Turbulence was expected at any altitude on airways, but since the selection of the flight altitude was left to me, I judged that flight 353 from Tokyo to Fukuoka would be in cloud but that turbulence would be slight, so I selected an altitude of 31,000ft.

“We took off from Haneda and leveled off at 31,000ft, but we were flying in cloud with continuous buffeting. There was a report from another aircraft flying at 39,000ft that it was smooth at that altitude, so I climbed to 35,000ft at first, but the conditions were the same as at 31,000ft. After that, on climbing to 39,000ft, we were over the tops of the clouds and air was stable.

“Considering the turbulence encountered in cloud during flight 353, the altitude for the return flight 356 from Fukuoka to Haneda was changed from the filed FL370 to FL410.

“I was flying the aircraft taking off from Fukuoka, and just before Oita VOR/DME we flew direct to FLUTE. There was no cloud or buffeting at 41,000ft.

“As this flight was on schedule, I flew in ECON speed mode, and began the descent at the TOD. The TOD was between FLUTE and a line abeam Yaezu (a horizontal line through Yaezu).

“Descending from 41,000ft on autopilot, at around 39,000ft there was a cover of slightly flattish stratus type clouds rather than cumulus. Rattling vibrations began as I thought we were entering cloud, and just as I was thinking ‘turbulence’, the trend indication on the airspeed indicator suddenly grew. Since it made a very large jump, I quickly made a speed intervention to keep us from accelerating. At first, IAS was indicated, and when the indication changed to Mach number it was indicating Mach 0.86. The captain thought our speed was still too high so he changed the setting to Mach 0.80. Our speed still hadn’t decreased after a short while, so the captain pulled the speed brakes, but even then speed didn’t decrease and there was a sudden pitch up accompanied by the stick shaker operating. I don’t remember what the time was then, but as the captain called ‘I have control’, I called ‘You have control’ and handed over PF duties to the captain.

“The autopilot was already disengaged when I checked it. I don’t know whether the captain intentionally disconnected it or whether it just disconnected on its own.

I made all operations such as speed intervention to decrease airspeed by MCP operation when I was performing PF duty. I neither made operations such as overriding the autopilot by control column, nor changed to manual control

“After the pitch up we entered a pitch down condition, and I felt some slight negative G at that time.

“After that, we descended for a while under manual control, then the captain ordered ‘Autopilot on’. I think the seatbelt sign was turned on by the captain when we encountered the turbulence.”

(3) The Assigned First Officer

“I was observing both flight 353 from Haneda to Fukuoka and flight 356 from Fukuoka to Haneda from the observer’s seat.

“During flight 356 the air was smooth at 41,000ft. We started the descent and rattling vibrations began at around 39,000ft and there was a speed increase tendency. Up to that time, the first officer had been assuming PF duties from the right seat.

“I didn’t monitor who made the speed intervention, but I think that the captain changed it from Mach 0.86 or 0.85 to Mach 0.80. Although he set the command to Mach 0.80, there was still a speed increase trend. I thought the captain used the speed brake, but because I was sitting behind him I could not see by how much.

“At that time, I felt sensations of pitching up and the stick shaker operated. Then, in too short a space of time to monitor carefully, the aircraft became nose down with slight negative G, and I felt a slight tendency to rise from my seat.

"Then, when we had reached around 38,000ft, the aircraft returned to a relatively settled state. I couldn't see from the rear seat when the autopilot became disconnected. I didn't recognize anything like autopilot-disconnect warning during that time.

"These events all happened in very short period of time, with about 1,000ft altitude difference between the onset of buffeting and things settling down. There was no time to monitor wind changes."

(Note 9): "ECON speed" is the economical operating speed, and is the speed normally used. The ECON speed at the time of the accident was around Mach 0.865. The maximum operating speed (Mmo) for Boeing 747-400 type aircraft is Mach0.92.

(Note 10): The "Trend Indication" is an arrow indicator mark on the airspeed tape of the Primary Flight Display (PFD: instrument installed on the left and right cockpit front panels that displays information relating to speed, attitude, control commands, autopilot status, altitude, vertical speed, heading and flight track) that shows the predicted airspeed ten seconds ahead based on the aircraft's current acceleration or deceleration.

2.2 Injuries to Persons

Four persons － three passengers and a CA － sustained serious injuries, and 29 persons － 18 passengers and 11 CAs － were slightly injured.
(See Figure 4)

2.3 Damage to the Aircraft

There was minor damage to the interior of the passenger cabin. Details of the damage are as follows. Numbers in parenthesis correspond to the locations indicated in Figure 5. (See Figure 5 and Photos 1, 2 and 3)

(1) Seats

The right armrest of seat 56G was deformed. (①)

(2) Ceiling panels

A ceiling panel above the right aisle near seat 56G was cracked and displaced from its original position. (②)

A ceiling panel above the right aisle near seat 47G was displaced upward and came to rest over the panel's locking latch. (③)

(3) Ducts

Lavatory and galley vent ducts behind the ceiling over the right aisle near seat 56G were crushed, adhesives at the vent fan junction were peeled away, and a distribution duct was displaced. (②)

2.4 Crew Information

2.4.1 Flight Crew

(1) Captain: Male, aged 40

Airline Transport Pilot License (Airplane)	Issued July 25, 1996
Type Ratings	
Airplane multiengine	Issued August 20, 1984
Boeing 747	Issued June 28, 1990
Boeing 747-400	Issued August 4, 1992
Class 1 Airman Medical Certificate	
Validity	Until January 28, 2003
Total flight time	7,270 hours 19 minutes
Flight time during previous 30 days	40 hours 22minutes
Total flight time on Boeing 747-400	4,569 hours 23 minutes
Flight time during previous 30 days	40 hours 22minutes
Captain proclamation for Boeing 747-400	Issued July 7, 1998

(2) First Officer: Male, aged 29

Commercial Pilot License (airplane)	Issued August 27, 1999
Type Ratings	
Airplane multiengine (land)	Issued August 27, 1999
Boeing 747-400	Issued November 1, 2001
Instrument Rating	Issued August 27, 1999
Class 1 Airman Medical Certificate	
Validity	Until March 18, 2003
Total flight time	457 hours 31 minutes
Flight time during previous 30 days	12 hours07 minutes
Total flight time on Boeing 747-400	148 hours 37 minutes
Flight time during previous 30 days	12 hours 07 minutes
First officer proclamation for Boeing 747-400	Issued August 13, 2002

(3) Assigned First Officer: Male, aged 36

Airline Transport Pilot License (Airplane)	Issued September 13, 2002

Type Ratings	
Airplane multiengine (land)	Issued July 27, 1992
Boeing 747-400	Issued November 19, 1993
Class 1 Airman Medical Certificate	
Validity	Until August 7, 2003
Total flight time	4,460 hours 56 minutes
Flight time during previous 30 days	30 hours 1 minute
Total flight time on Boeing 747-400	4,180 hours 6 minutes
Flight time during previous 30 days	30 hours 1 minute
First officer proclamation for Boeing 747-400	Issued May 10, 1994

2.4.2 Cabin Attendants

(1) Chief Purser: Female, aged 35

Assigned Station	L1 door, Compartment A
Total flight time	9,694 hours 59 minutes

(2) Cabin Attendant A: Female, aged 35

Assigned Station	R1 door, Compartment A
Total flight time	8,747 hours 00 minutes

(3) Cabin Attendant B: Female, aged 31

Assigned Station	L2 door, Compartment B
Total flight time	5,776 hours 58 minutes

(4) Cabin Attendant C: Female, aged 34

Assigned Station	R2 door, Compartment B
Total flight time	7,378 hours 50 minutes

(5) Cabin Attendant D: Female, aged 37

Assigned Station	L3 door, Compartment C
Total flight time	12,572 hours 03 minutes

(6) Cabin Attendant E: Female, aged 41

Assigned Station	R3 door, Compartment C
Total flight time	11,507 hours 59 minutes

(7) Cabin Attendant F: Female, aged 34

Assigned Station	L4 door, Compartment D
Total flight time	6,841 hours 12 minutes

(8) Cabin Attendant G: Female, aged 38

Assigned Station	R4 door, Compartment D
Total flight time	9,871 hours 27 minutes

(9) Cabin Attendant H: Female, aged 39

Assigned Station	L5 door, Compartment E
Total flight time	11,094 hours 26 minutes

(10) Cabin Attendant I: Female, aged 30

Assigned Station	R5 door, Compartment E
Total flight time	5,842 hours 02 minutes

(11) Cabin Attendant J: Female, aged 41

Assigned Station	UL door, Upper deck
Total flight time	13,861 hours 48 minutes

(12) Cabin Attendant K: Female, aged 37

Assigned Station	UR door, Upper deck
Total flight time	8,234 hours 44 minutes

2.5 Aircraft Information

2.5.1 The Aircraft

Type	Boeing 747-400D
Serial Number	26345
Date of manufacture	August 17, 1991
Certificate of Airworthiness	99-031
Term of validity:	Until valid data of JAL Maintenance Program Manual from January 13, 1999
Aircraft Category	Airplane Transport (T)
Total time in service	21,525 hours 32 minutes
Flight time since scheduled maintenance "7C" Check on December 6, 2001	1,927 hours 43 minutes

(See Figure 2)

2.5.2 The Engines

Model: General Electric CF6-80C2B1F

	No. 1	No. 2	No. 3	No. 4
	702223	702218	706236	704951
Manufacture Date:	July 18, 1989	July 11, 1989	October 11, 2000	September 16, 1999
Total Time:	37,534hr 19min.	41,471hr 23min.	6,966hr 19min.	11,706hr 13min.

2.5.3 Weight and Center of Gravity

The weight of the aircraft at the time of accident is estimated to have been approximately 519,000lbs, with the center of gravity at 21.0% MAC, both being within allowable limits (maximum take-off weight being 574,000lbs, with the allowable range of center of gravity corresponding to the estimated weight at the time of accident of 13% to 30% MAC).

2.5.4 Fuel and Lubricating Oil

The Fuel on board was JET A-1. The lubricating oil was Mobil Jet-Oil II.

2.6 Meteorological Information

2.6.1 Weather Synoptic

The weather synoptic for October 21, 2002 issued by Nagoya district Weather Service Center at 05:00 JST was as follows:

> A developing low pressure system with a front offshore the Kii Peninsula is moving east-northeast, bringing rain throughout the Tokai Region. Today in the Tokai Region, it will rain until the afternoon because of the low pressure system passing offshore of Tokaido, but it is expected to become fine in the evening.

Further, according to the Surface Weather Analysis at 09:00 JST on October 21, 2002, a developing low pressure of 1,002hPa over the sea southeast of the Kii Peninsula was moving northeast at 20km. A warm front stretched to the east and a cold front extended southwest to over the sea south of the island of Kyushu. The low pressure system had moved over the sea east of the Kanto Region at 15:00 JST and had developed to 996hPa.
(See Figures 6-1 and 6-2)

2.6.2 Weather Satellite Cloud Imagery

The weather satellite cloud imagery (water vapor imagery) issued at 11:00 JST on October 21, 2002 confirmed convective activity over and offshore the Tokai Region.

2.6.3 Cloud Information Chart

According to the cloud information chart at 09:00 on October 21, 2002, a convective cloud zone including cumulonimbus extended from the Kii Peninsular and Tokai region to the Izu islands moving east-northeast.

(See Figure 8)

2.6.4 Nagoya Radar CAPPI and Echo Information

According to the CAPPI chart of the Meteorological Agency's Nagoya Radar at 11:00 JST on October 21, 2002, there were no weather echoes observed at altitudes of 10km and 8km, but weather echoes were confirmed offshore of the Kii Peninsula and offshore of Omaezaki at an altitude of 6km. However, almost no echoes were observed offshore of Hamamatsu City.

(See Figure 9)

2.6.5 Aerology

At 21:00 JST on October 20, 2002, the day prior to the accident, there was a cold low pressure system east of Lake Baikal, and an associated trough moving slowly east. There was a strong wind zone observed southeast of the low pressure system, and also a strong wind zone near Hokkaido. Moreover, at the bottom of the strong wind zone to the southeast, there was a trough connected to the low pressure system on the ground and proceeding to the east.

The extreme wind, altitude where the extreme wind were observed and potential temperature(Note 11) at the altitude at an aerological observation point near the strong wind zone southwest of the low pressure system at 0900 JST and 2100 JST on October 21, 2002, are indicated in the table below. (The figures in parentheses in the 2100 JST wind speed column indicate the wind speed difference from the 0900 JST observations.)

Observation Point	0900 JST on October 21			2100 JST on October 21		
	Altitude (hPa) (Note12)	Extreme Wind direction (°)/speed (kt)	Potential Temp. (K)	Altitude (hPa) (Note12)	Extreme Wind direction (°)/speed (kt)	Potential Temp. (K)
Fukuoka	193–183	265/109	355–358	224–158	275/107(–2)	345–363
Kagoshima	236	270/96	347	259–246	280/111(+15)	343
Yonago	151	265/101	370	152	260/105(+4)	370
Shionomisaki	172–164	265/93	357–361	162	260/107(+14)	363
Hamamatsu	176–167	260/97	355–360	189–180	255/107(+10)	360–364
Wajima	160	255/93	363	179	250/95(+2)	348
Tateno	248	245/86	335	195	240/97(+11)	357
Hachijo Island	191–181	275/80	350	205	255/93(+13)	355

(See Figure 10, 11, and 12)

(Note 11): "Potential temperature" is the temperature that a dry parcel of air would have if transformed adiabatically from its ambient temperature and pressure to a pressure of 1000hPa, and is expressed on the absolute temperature scale. Using potential temperature, it is possible to compare the warmth of air at different altitudes.

(Note 12): "Altitude (hPa)" is altitude expressed as atmospheric pressure. Using the Standard Atmosphere, 200hPa is approximately 38,800ft, 250hPa is approximately 33,950ft, and 500hPa is approximately 18,200ft. 41,000ft is approximately 178hPa, and 39,000ft is approximately 196hPa.

2.6.6 Turbulence Information

(1) Briefing by the dispatcher who compiled the flight plan

The following is a summary of the statement of the dispatcher at Haneda who briefed the captain and his crew for flights 353 and 356 of the round trip to Fukuoka.

"At 06:00, I briefed the captain and his crew for flights 353 and 356 of the round trip to Fukuoka. I used the latest weather information at the time. As there were no domestic flights operating at that time, there were no reports from other pilots on Fukuoka flights.

"For the round trip to Fukuoka, there was widespread cloud and scattered echoes, and the forecast significant weather chart indicated slight turbulence in flight through cloud, but since CAT (clear air turbulence) was not forecast, I did not brief on CAT."

(See Figure 13)

(2) In-flight Information

According to the aircraft's flight crew, there were only two reports relating to turbulence that concerned flights 353 and 356 of the round trip to Fukuoka:

① During flight 353 to Fukuoka, there was an ACARS report of TB4 turbulence encountered at 35,000ft near Kushimoto.

② During flight 356, there was an ACARS report of TB4 turbulence encountered at 37,000ft over FLUTE (reporting point).

2.7 Communications

The aircraft's radio was tuned to Tokyo Control Kanto South C Sector radio frequency from the start of its descent until the occurrence of the accident. Radio communication conditions were satisfactory.

2.8 DFDR and CVR Information

(1) DFDR

The aircraft was equipped with a Honeywell DFDR (Part Number 980-4700-033). Data recordings were normal.

The time recorded by the DFDR is derived from a radio broadcast time signal. Comparison of the radio time signal with the NTT time signal recorded on ATC communication recordings at ATC facilities showed that these times were consistent.

In the analysis, data recorded on the aircraft's ACMS were used to supplement data not recorded by the DFDR.

(2) CVR

The aircraft was equipped with a Honeywell CVR (Part Number 980-6022-001) which has a 120-minute recording time. Voices and sounds were recorded normally.

The CVR time was synchronized with the DFDR time by comparing VHF transmission keying data recorded on the DFDR with time information in ATC communication recordings.

2.9 Medical Information

2.9.1 Circumstances of Serious Injuries

Summaries of the extents of injuries to the three passengers and one CA who were seriously injured and their statements regarding the circumstances under which they were injured are as follows.

(1) Passenger, male aged 37 (seat 43K)

Location and extent of injuries: Fracture of right collarbone, bruising of right arm.

Summary of statement: While taking a nap without my seatbelt fastened, there was a rattling noise and a sideways shaking so I tried to leave my seat but I floated to the ceiling and hit my shoulder hard on the floor when I fell.

(2) Passenger, male aged 31 (seat 47E)

Location and extent of injuries: Fracture of right hip, bruising of right arm.

Summary of statement: I was sitting without my seatbelt fastened when there was a loud noise and I felt I was being thrown upwards as I floated up to the ceiling. I then hit my back hard on the armrest when I fell.

(3) Passenger, male aged 36 (seat 56F)

Location and extent of injuries: Impact to neck vertebrae

Summary of statement: While sitting without my seatbelt fastened, I floated up and my neck and shoulder hit the ceiling. After that, I fell down into the aisle near seat 58H.

(4) CA-E, female aged 41 (working in the aft galley)

Location and extent of injuries: Bruising of head and back, concussion of the brain.

Summary of statement: The drink service had finished and I was in aft galley preparing for the next cabin service when there was a big jolt. Although I grabbed the galley handrail with both hands and squatted down, I floated up to the ceiling in an instant and hit my head against the ceiling. Immediately afterward, I fell to the floor and hit my head and back hard.

2.9.2 Circumstances of Minor Injuries

Summaries of the circumstances of minor injuries collated from the statements 18 passengers and 11 cabin attendants who sustained minor injuries are as follows.

(1) Passengers

When the turbulence was encountered, passengers sustained injuries due to floating upwards while in the lavatory and striking their heads etc. on the ceiling, floating upwards while walking in the aisle just before resuming their seat and hitting their heads on the ceiling, and floating out of their seats and hitting their heads etc. either on the ceiling or on the floor when they fell.

Of the eighteen passengers who were slightly injured, fifteen passengers had been seated when they were slightly injured. Six of those had had their seatbelts fastened, seven had not fastened their seatbelts, and the seatbelt usage of two passengers could not be confirmed. Three of those who had fastened their seatbelts had fastened them loosely.

(2) Cabin Attendants

Two CAs on the upper deck, two CAs near the forward galley, two CAs near the mid galley, and three CAs at the aft galley were making cabin sales and tidying up the cabin service, and while a further two CAs near the R3 door were making cabin sales. These CAs were injured when they floated up during the turbulence encounter and struck their heads, etc. on the ceiling, or when struck their backs etc. on the floor while grabbing handrails to avoid floating upwards or when they fell to the floor.

Those CAs who were working in the aft cabin struck the ceiling or floor hard and were injured by the impact.

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

2.10.1 The Situation in the Cabin before and after the Accident

The following are summaries of the situation in the passenger cabin before and after the turbulence encounter according to the statements of the captain, CAs and passengers.

(1) The Captain

"While descending at 39,000ft, there was a sharp increase in speed, I pulled speed brake lever, and called "I have". After I felt the aircraft pitch up, the stick shaker operated, and I pitched the aircraft down. At the time I felt negative G force lifting me gently. After that, I confirmed that the aircraft was stable, turned on the seatbelt signs, and also made a passenger announcement to fasten seatbelts.

"I called the Chief Purser and asked her to report the situation in the cabin.

"I received many reports from the cabin; one passenger was bleeding, passengers had bruised their shoulders, etc., a cabin attendant had been injured, and part of the ceiling had fallen down.

"Since I'd been informed that a person was bleeding, I called the company Haneda Airport Office on the company radio and requested an ambulance stand by.

"There were cabin crew requests to allow them to treat the injured, clear up the cabin etc., and judging that there would be no further severe turbulence and thinking that leaving the seatbelt signs on would impede the cabin crew administering first aid, I switched the seatbelt signs off before we descended to 16,000ft. We then continued a normal descent while the CAs were administering treatment."

(2) Cabin crew

The cabin crew had all boarded flight 353 with the flight crew for the round trip between Haneda and Fukuoka. Before the departure of flight 353, they were briefed by the first officer and advised to use caution when providing cabin service as turbulence was expected for the first 30 or so minutes after take-off.

Prior to the return flight 356, they were briefed by the first officer that as turbulence was expected for around 30 minutes after take-off the seatbelt signs would be on, but no significant turbulence was expected thereafter. They were also informed of the change in altitude from FL370 to FL410, etc.

A little while after the severe disturbance the seatbelt signs came on and the cabin crew made a cabin announcement to fasten seatbelts, immediately followed by a similar announcement to fasten seatbelts from the flight crew.

The Chief Purser was ordered by the flight crew to report the situation in the cabin, and on asking the CAs in each section to confirm the situation in their part of the cabin, she was told of a bleeding passenger in aft cabin, a passenger who had sustained bruising of the shoulder, and an injured CA, and she reported these to the flight crew. Although a call for a doctor was requested from the aft cabin, the Chief Purser replied that it would be impossible at that moment because the seatbelt signs were still on. Meanwhile, first aid was administered to the injured passengers in aft cabin.

Summaries for each cabin compartment are as follows.

① Upper deck

"The drinks service and cabin sales had finished on the upper deck, and while clearing up, there was buffeting but not to an extent that it would have been necessary to resume seating. After that there was rattling vibration but not to an extent that would disturb service, but then in an instant there came a strong jolt to make bodies float as if in space. At the time, the CAs in galley grasped handrails with one hand, but floated up gently to the ceiling feeling as if weightless, hit their heads on the ceiling, fell to the floor, then squatted down. I saw a book, which I suppose flew out from a pocket of a seat in front of the galley, fall from the ceiling. A CA going down the stairs to the main deck grabbed the stairway handrail with both hands, but she floated up like on the parallel bars in gymnastics and then fell into the stairway. The passengers in the upper deck seem to have had their seatbelts fastened, so nothing in particular happened to them."

② Aft section of main cabin

Four CAs were tidying up in the aft galley after cabin service. There was an unusual vibration and a noise like the earth rumbling, then suddenly there was a strong jolt and all four CAs floated up in the air and hit their heads against the ceiling and galley handrails, injuring one of the CAs. After that, the seatbelt signs came on so the CAs made an announcement to fasten seatbelts, but then realized that injuries had occurred near seats 43H and 58H in the aft cabin, so they made an announcement calling for a doctor. They then administered first aid to the injured with the help of a doctor and a nurse who had come forward. Because the injured passenger near seat 58H was not in a condition to resume his seat, the aircraft landed with him secured to the seats lying on his back.

③ Mid section of main cabin

CAs who had been conducted cabin sales near the R3 door in the main cabin felt an unusual sideways shaking, then after they had been pushed momentarily with a sound of 'Garr', they floated up and one of them hit her head against the ceiling.

According to a CA who was looking aft from the forward galley, a cart floated up around 1m. Thereafter, she locked the cart stop bars, and each CA assumed her respective jump-seat nearby. At that time, as the seatbelt signs came on, she made an announcement for standing passengers to be seated, and reported to the CP that there were no injuries in the D compartment (between the R3/L3 doors and the R4/L4 doors), and no problems in the lavatories.

④ Forward section of main cabin

While two CAs were tidying up in the mid galley after cabin sales, there was a sideways shaking and a jolt from below pushing them upwards and they felt as though they were being thrown to the ceiling so they grabbed galley handrails with both hands and held on tightly so as not to float upwards. After that, they assumed their respective jump-seats.

Almost of all of the passengers in the C compartment (between the R2/L2 doors and the R3/L3 doors) were sleeping with their seatbelts fastened.

(3) Passengers

According to a passenger who had been seated in the aft cabin without seatbelt fastened and sustained serious injuries, the passenger made one child sit in the adjacent seat with seatbelt fastened, and just as the passenger had raised the armrest and was making another child sit in the space between the passenger and the child on the adjacent seat, there was a large jolt and the passenger floated up to the ceiling with the child. The passenger felt stopped for a while, but then I fell to the floor in the aisle. As the child on the adjacent seat had its seatbelt fastened, it did not float up.

According to another seriously injured passenger who had been sitting in the aft cabin, they felt two or three sideways shakes and just as they were thinking that it was shaking a little, they floated to the ceiling and fell into the aisle feeling as if being thrown down. The passenger did not have their seatbelt fastened.

According to passengers on the upper deck, personal computers on their knees floated up a little, and even one of the passengers who had fastened their seatbelts had part of their body lifted gently.

2.10.2 The Response of the Company and Emergency Facilities

At around 11:10, the Passenger Department of Japan Airlines' Haneda airport office received information that the aircraft had encountered turbulence, that persons had been injured, and that an ambulance was being requested. The Passenger Department made a 119 call to the emergency services at around 11:16, reporting that 3 passengers had been injured due to turbulence, that the scheduled time of arrival was 11:24, that the aircraft would arrive at spot 12, and that they would meet them at gate 4 of the terminal building.

According to the Tokyo Fire Fighting Bureau, the general headquarters office received the above information and dispatched one ambulance each from the Kamata Fire Fighting Station (KFFS), the Haneda Branch Office of KFFS and the Sanya Branch Office of the Oomori Fire Fighting Station (OFFS), a KFFS Command Team command vehicle, and a fire engine from the KFFS Airport Office. These arrived at the designated gate 4 between 11:29 and 11:34.

The aircraft arrived at spot 12 at 11:29, and the ambulances and emergency vehicles arrived beside the aircraft at around 11:36. Because the passengers were disembarking, rescue activities in the cabin were started after waiting for disembarkation. Just as rescue activities in the cabin were starting, JAL reported that there were a total of nine injured persons including the three initially reported, so a request for an additional two ambulances was made to the general headquarters office at around 11:50.

The general headquarters office ordered the Airport Office of KFFS and the Magome Office of OFFS to each dispatch one ambulance, and these arrived in front of gate 4 at around 12:05 and around 12:16. Subsequent rescue activities confirmed a total of 14 injured, and a further request for ambulance dispatch was made to the general headquarters office at around 12:18. An ambulance from Yanokuchi Fire Fighting Station ordered by the general headquarters office arrived at around 12:40.

A total of 19 persons — 12 passengers including persons who complained of being in a bad condition, and seven CAs, were admitted to hospital. Afterwards, a further nine passengers who complained of being unwell received treatment at hospitals near their homes, and five CAs received treatment at JAL's clinic.

2.11 Tests and Research to Find Facts

2.11.1 Investigation of Weather Conditions

(1) Convective cloud condition

According to the nephanalysis information chart for 09:00 JST on October 21, 2002 in Figure 8, there was a convective cloud zone including cumulonimbus stretching from offshore the Kii peninsula and near Izu Islands through to offshore the Tokai region and proceeding east-northeast. According to the CAPPI chart issued by Meteorological Agency's Nagoya radar at 11:00 JST on October 21, 2002, in figure 9, while echoes were observed at an altitude of 6km, there were no echoes from 8km upwards.

(2) Movement of subtropical jet stream

According to the 200hPa weather chart for Asia in figure 10, there was strong wind zone (shaded) of 120kt or greater accompanying a subtropical jet stream (shown as s～s' in the chart), and a polar jet stream (shown as p～p' in the chart) at the latitude of Hokkaido. The potential temperatures of these jet streams differed; the potential temperature of the former was around 355–360K, and the potential temperature of the latter was 330K.

The subtropical jet stream s～s' was proceeding east from 21:00 JST on October 20 (12:00 UTC on October 20) to 21:00 on October 21, the date of the accident. Looking at the isopiestic curve of 100kt and the tip of the subtropical jet stream s', the subtropical jet stream s' proceeded east along the south coast of the island of Honshu, and was passing through point where the accident occurred between 09:00 and 21:00 on October 21.

The subtropical jet stream had a potential temperature of 355–360K. According to observations of extreme wind altitude and potential temperature at the aerological observation points in section 2.6.5 at 09:00 and 21:00 on October 21, points satisfying the jet stream conditions were at Shionomisaki, Hamamatsu, Hachijo Island and Fukuoka. Further, the tip of the subtropical jet stream s' passed those four points from 09:00 through 21:00 on the day of the accident; that is, the jet stream had already passed through Fukuoka at 09:00 on the same day, and there were wind increases at the three points of Shionomisaki, Hamamatsu, and Hachijo Island. Furthermore, as shown in the section 2.6.5, the altitude of the extreme wind became lower at Hamamatsu and Hachijo Island.

Considering the above, it is estimated that at around the time the subtropical jet stream s' passed over the point of the accident, the wind became stronger and the extreme wind moved to a lower altitude.

(3) Trough below the subtropical jet stream

According to the 500hPa weather chart for Asia in figure 11, a trough (valley of atmospheric pressure) was passing below the subtropical jet stream.

As shown in figure 12, the trough, indicated by a T in the 250hPa weather chart, was over the east coast of the island of Kyushu at 09:00 on October 21, but was not in the 200hPa weather chart for Asia. The trough in the 250hPa weather chart proceeded east and was at the position T' at 15:00 on October 21, and the trough in the 200hPa weather chart was the virtually same position as the trough in the 250hPa weather chart for 15:00 on October 21; that is, at 21:09

the trough had not reached an altitude of 250hPa, but had developed up to an altitude of 200hPa at 15:00.

(4) Vertical wind shear in aerology observations

Figure 14 shows the temperature and the wind speed distribution observed over Hamamatsu at 09:00 and 21:00 on October 21, 2002. According to this chart, the vertical shear (vector) near the altitude at which the accident was the average between point m (altitude 176hPa, wind 260°/97kt) and point n (altitude 200hPa, wind 255°/86kt) and was small at around 5kt/1,000ft at 09:00 on October 21. At 21:00 on October 21, it was around 8kt/1,000ft in the narrow observed altitude band of 189–200hPa below the jet stream.

From the above, aerology observations around the altitude that the aircraft was flying at the time of the accident could not confirm the existence of strong vertical shear.

(5) Vertical wind shear based on ACMS data

① Assumption

When an aircraft is flying in turbulence, there are many vortices in the airflow and since the airflow is disturbed, it is difficult to determine from the severe wind changes recorded each second in the ACMS data the basic steady wind values necessary to predict Kelvin-Helmholtz instability (Note 13), which causes windshear and Clear Air Turbulence. Consequently, it was assumed that periods in which aircraft's vertical acceleration deviated from 1G by less than ±0.1G for more than three seconds were considered as points in time where the airflow disturbance was small, and so wind data for these periods could be considered to indicate the underlying steady wind. Wind data that met this criterion were selected, and the arithmetic mean for the wind over the three-second periods was calculated.

Temperature data were recorded at two-second intervals, and so the average of the values at the start and end of each interval were calculated. The results of these calculations are plotted in figure 14.

② Vertical wind shear

The following were determined by plotting the winds calculated in ① above.

a. According to the table in section 2.6.5, the extreme wind (jet stream) over Hamamatsu was descending at a rate of around 1hPa/h over a twelve-hour period from 176–167hPa at 09:00 on October 21 to

189–180hPa at 21:00.

The vertical distribution of wind at the time the accident occurred is almost parallel to a line between points m and n at 09:00, as indicated by the solid line k, and the lower altitude limit of winds with the same wind speed distribution gradient as at 09:00 is indicated by the point P (altitude 39,807ft, wind 258°/100kt). This shows that the effect of strong winds associated with the jet stream reached this altitude.

b. The wind speed of the strong wind zone indicated by the solid line k that appears in the ACMS data is almost exactly the middle of the speed of the strong wind zone indicated by the line connecting point's m and n at 09:00 and the speed of the strong wind zone observed at 21:00. That is, the wind speed increased rapidly from 09:00 until the time of the accident around two hours later.

c. The direction of the wind at around 39,000ft observed at point n at 09:00 was 225°, but the wind direction based on ACMS data up to an altitude near point Q (altitude: 38,847ft) at the time of the accident was 246–248°, indicating that the wind had shifted 7–9° to the south since 09:00, and wind speed fell to 246°/78kt at point Q.

As described in (3) above, there was a trough below the jet stream, and while that had not reached an altitude of 250hPa at 09:00, it developed upwards while proceeding east, and had reached up to 200hPa at 15:00. There was updraft in front of the trough, which can be confirmed in meteorological satellite cloud image (water vapor image) in figure 7. Due to this updraft, the low-speed prevailing lower layer wind with a southerly component was transported upward, and the upper limit for the wind of 240° at point S (250hPa) in figure 14 at 09:00 became a direction of 246–248° up to the altitude of point Q (200hPa) at the time of the accident, but with a speed reduced by around 8kt compared with the value at 09:00.

d. The vertical shear at the time of the accident computed from ACMS data was as follows:

- Using points P and Q in the ACMS data in figure 14:

  The vertical wind shear was computed using data in the interval between point P, which is the lower limit of the downdraft of the strong wind associated with the jet stream and point Q, which is the upper limit of winds having a southerly component.

  The vertical shear was computed as around 30kt/1,000ft.

- Using points R and Q in the ACMS data in figure 14:

  Since the acceleration experienced by the aircraft was small up to the point R (altitude: 39,367ft, wind: 255°/95kt), which is just below point P and after a two-second period in which vertical acceleration exceeded 1G ±0.1, this analysis used data in the interval between point R and point Q.

  The vertical shear was computed as around 40kt/1,000ft.

(6) Rapid wind changes at a single altitude

Based on the ACMS data, the wind was 252°/90kt at 39,127ft at 10:57:36, but changed quickly to 247°/78kt at 39,130ft at 10:57:38.

(Note 13): "Kelvin-Helmholtz instability" is an instability that develops in the interface between two fluids moving at different horizontal speeds (i.e. shear) when the speed difference between the fluids exceeds a critical value depending on the difference in density between the fluids. The resulting wave motion is called a K-H wave. It may occur even if a light fluid moves over a static, stable heavy fluid, and is considered the cause of many instances of Clear Air Turbulence.

2.11.2 Winds experienced by the Aircraft during descent

To obtain the wind data necessary to carry out the numerical simulations described in section 2.11.7, the wind vector was obtained from the ACMS data as the difference between the ground speed vector and the airspeed vector with compensation for the effects of the aircraft attitude changes, and the direction and speed of the winds that the aircraft encountered around the altitude at which the accident occurred were computed. Details of the results of this computation are given in Appendix 2.

The tail wind component on the aircraft decreased by around 30kt during the approximately five seconds immediately before the accident occurred. And the wind direction changed by approximately 10° at that time. As a result, the aircraft's airspeed (CAS) increased rapidly by approximately 20kt. The vertical wind speed was computed as ±8kt.

2.11.3 Boeing 747-400D Longitudinal Flight Control System

(1) Elevators and Elevator Drive System

The Boeing 747-400D has split elevator surfaces with four elevator sections — one inboard and one outboard section on each side. Each inboard section is driven by a tandem-type PCP powered by two of the aircraft's four hydraulic systems, while each outboard section is driven by a simplex-type PCP powered by a single hydraulic system. Movement of an inboard elevator section is transmitted through a slave link to the PCP of the outboard elevator section on the same side, so that the outboard sections follow the movement of the inboard sections.

The left and right inboard elevator sections are always at the same surface angle, as do the left and right outboard elevator sections. The inboard sections are controlled so that their trailing edges are always deflected upward 2° more than the outboard sections. When the control column is in the neutral position, the inboard sections are deflected 1° trailing edge up and the outboard sections are deflected 1° trailing edge down. The elevator control movements of the pilot and autopilots are applied to a single torque tube installed near the elevators, and the movement of the torque tube is transmitted to the PCPs that drive the left and right elevators through a linkage mechanism.

The elevators can travel through a total range of 40° between 25° nose up and 15° nose down.

(2) Elevator feel system

The elevator feel system provides artificial control feel for the elevators. The elevator feel system helps prevent the pilot from over-controlling the aircraft by increasing the control force necessary for the pilot to apply according to airspeed (dynamic pressure), and by preventing the control feel from changing with aircraft CG position changes.

(3) Stick Shaker

Stick shakers are installed on the control columns to warn when the aircraft's airspeed is approaching the stall speed. The conditions for stick shaker to operate vary according to angle of attack measured by vanes, pitch rate, flap setting, Mach number, speed brake position and the position of landing gears.

2.11.4 Boeing 747-400D Manual Elevator Control

The two control columns are connected by a torque tube. Forward and after movement (descent and climb) of the control columns is transferred to a forward crank located under the cockpit, and is further transferred to aft quadrant behind the horizontal stabilizer by control cables.

The movement of the aft quadrant is input to the tandem PCPs by control rods, operating the inboard elevator sections, and the movement of the inboard sections is input to the simplex PCPs via the slave links, operating the outboard elevator sections.

The elevators may be moved by manual control at a maximum rate of 50°/s.

2.11.5 Boeing 747-400D Autopilot Elevator Control

The Boeing 747-400 is equipped with three autopilots – left, center and right. All three autopilots are engaged simultaneously during auto-approach and landing (below 1,500ft), but in other flight modes only a single selected autopilot is engaged.

(1) The actuators of the three autopilot systems (left, center and right) move the aft quadrant of the elevators by an amount computed by the Flight Control Computer (FCC). Each actuator is driven by a different hydraulic system.

The movement of elevators by the autopilot actuators is fed back to the control columns through the torque tube installed near the elevators and elevator cables connected to the torque tube; that is, when autopilot is controlling the elevators, the control columns move in response to the motion of the elevators.

(2) Autopilot elevator control authority is limited according to speed, horizontal acceleration, vertical acceleration and vertical acceleration due to pitch attitude changes. Autopilot pitch control in VNAV mode is limited to within ±0.15G incremental vertical acceleration. And also, autopilot pitch command in VNAV mode speed protection in the area near Vmo/Mmo is also limited to within ±0.15G incremental vertical acceleration.

(3) Manual Override of Autopilot

"Manual override" means that when the autopilot is engaged, a force applied by the pilot to the control column makes the control surface angle different from that of the autopilot command. The term "manual override" is used with this meaning in the remainder of this report.

With the Boeing 747-400D airplane, when only one autopilot is engaged, the pilot can manually override the autopilot by applying a force on the control column. The autopilot does not disengage due to the manual override.

If the pilot applies a force to the control column and manually overrides the autopilot when only one autopilot is engaged, the FCC monitors the autopilot servo positions and elevator angles issues an autopilot caution if they disagree for more than six seconds (amber "AUTOPILOT" caution message displayed on the EICAS (Engine Indication and Crew Alerting System) display, aural warning, and illumination of the master caution light).

(4) VNAV/PTH mode

Descent in VNAV/PTH mode is used in order to pass over a fix on the flight route at an assigned altitude.

While descending in VNAV/PTH mode, if the flight path angle changes due to changes in the wind, etc. autopilot controls the aircraft's pitch attitude using the elevators to maintain the aircraft on the planed FMC descent path.

(5) VNAV/SPD mode

In the descent in VNAV/SPD mode, the autopilot controls the aircraft's pitch attitude using the elevators to maintain the target speed.

(6) Speed Intervention

Speed intervention means that the pilot temporarily changes the autopilot command speed controlled by the FMC by operating the MCP.

While the autopilot pitch mode is a VNAV mode, pushing the MCP IAS/MACH selector changes the IAS/MACH window between open and closed. When the window is open, FMC speed intervention is enabled and the command speed may be selected on the IAS/MACH selector. When speed intervention is used while descending in VNAV/PTH mode, the autopilot pitch mode changes to VNAV/SPD and the autopilot controls the aircraft's pitch attitude using the elevators to maintain the selected speed.

When the IAS/MACH window is closed, the autopilot controls the aircraft's pitch attitude using the elevators to maintain the target speed computed by the FMC.

(7) Speed used by the Autopilot

Speed data from the Air Data Computer (ADC) includes short period variations induced by turbulence and atmospheric instability. To minimize the effects of this, the raw airspeed data is filtered and this filtered speed data is used for speed control by the autopilot. In the VNAV SPD mode, this filtering is part of computation of the pitch commands in the FMC. Therefore, the speed used in the VNAV SPD mode is different from the speed displayed on the PFD which is seen by the pilot. During descent path tracking in the VNAV mode, the autopilot will transition from VNAV PTH mode to the VNAV SPD mode as the airspeed approaches 11kt below Vmo/Mmo. When the VNAV SPD mode becomes active for speed protection, the Autopilot controls speed to 16kt below Vmo/Mmo as a target speed.

2.11.6 Autopilot Tests performed after the Accident

The following tests were conducted on the autopilot after the accident, but no anomalies were found. Further, regarding the autopilot's disengaging at the time of the accident, the statements of the flight crew contained no mention of symptoms or instrument indications that would indicate a problem with the autopilot.

(1) Post-flight inspection of autopilot condition

No autopilot faults or problems had been recorded in the flight logbook at the time of the accident and on the previous flight.

No autopilot anomaly was recorded by the ACMS during the accident flight, and there was no record of an autopilot caution. Further, checking the autopilot's condition using the EICAS during the post-flight inspection showed no indication of faults, etc.

(2) Functional test of engagement and disengagement

Electrical and hydraulic power was supplied to the aircraft and autopilot engagement and disengagement was tested.

After engaging the autopilot, the disengage switch on the control wheel was pushed once, and the autopilot disengaged, the master warning light illuminated, and an aural warning (siren) sounded. On pushing the disengage switch a second time, the master warning light went out, and the aural warning (siren) stopped.

This was normal behavior as described in AOM.

Further, there was no aural warning (siren) sound in the CVR recording at the time when the autopilot disconnected.

2.11.7 Numerical Simulation of Aircraft Motion

To confirm the flight conditions around the time the accident occurred, after examination of the DFDR and ACMS data, it was confirmed that the aircraft motions could be reproduced by numerical simulation, and then numerical simulation was used to analyze the effects of pilot control inputs and wind changes on the aircraft motions at around the time of the accident. These studies are summarized below. (See Appendix 3)

(1) Recorded Data

① Selection of data for motion analysis

Since the ACMS records many more parameters than the DFDR, and since the AMCS recording rate (number of samples recorded per hour) is higher for some parameters important for motion analysis, ACMS data was used for the motion analysis.

② Consistency of ACMS data and DFDR data

A time shift between the data recorded on the ACMS and the DFDR was corrected based on vertical acceleration data which are recorded at a high rate.

As a result, it was found that CAS, aircraft pitch angle θ, control column angle δ_{col}, and the elevator surface angle δ_e all four surfaces nearly coincided in the ACMS data and DFDR data. The data for θ, and δ_{col} in the DFDR recording was delayed slightly with respect to the ACMS recording, but the signal shapes was virtually identical. Consequently, it is thought that there is no discrepancy between the ACMS data and the DFDR data.

(See Figure A in Appendix 3.)

③ Speed Brake Data Recording

The statements of the flight crew, including that of the captain, mentioned the use of speed brakes or the possibility that the speed brakes were used, but the data for speed brake lever in the period of the time relevant to the accident indicated zero; that is, it was in the 'retracted' position. Further, the recordings for the No. 4 spoiler panels, which operate as speed brakes, were always in the zero position.

Since the ACMS records speed brake data at 1Hz (once a second), speed brake operation might not be recorded if the operating time is less than one second. Further, the DFDR recording rate is also 1Hz, but there was no recording of speed brake lever movement during the relevant time period.

④ Elevators

The following discrepancies were found in the ACMS elevator surface angle data.

a. During a time in which there was significant movement of the elevators, in particular during the two seconds period 1057:42–43 just after autopilot disconnected, the movement of inboard elevators was around 7° greater than the outboard elevators. Further, there was a difference between the surface angles of the left and right elevators surface angle of greater than 1°, and attained 3°. It is difficult to think that these differences arose due to the elevator drive mechanism.

   (See Figure B in Appendix 3.)

b. There was an almost linear relationship between the travel of the inboard elevators and the movement of the control columns. However, during the two-second period 1057:42–43, the surface angles of the outboard elevators was nearly constant (approximately 5° and 7° trailing edge down) against a control column position of over 8°, and was not linear with control column position.

   (See Figure C in Appendix 3.)

⑤ Horizontal stabilizer

According to the opinion of the aircraft manufacturer, during the time from just before the autopilot disconnected at around 1057:41 until around 1057:54, it was pointed out that considering that there was no recording of command signals issued to make the horizontal stabilizer (stabilizer) travel up and down, and that the stabilizer mechanism cannot move the stabilizer as rapidly as the position data indicate, it is possible that the changes in stabilizer position in the data are not due to actual shifts in the stabilizer position, but are recordings of elastic deformation, etc.

Since stabilizer position is recorded once every two seconds, the stabilizer position during the period while the data is varying as described above was determined to be its position at 1057:41.

(2) Reproduction of aircraft motion by numerical simulation

To reproduce the aircraft motions, numerical simulations were conducted for two cases: ① using the raw elevator surface angle time history from the ACMS, and ② using the outboard elevator surface angle time sequence data from the ACMS for the movement of both inboard and outboard elevators. Based on the considerations in section 2.11.7(1)③, it was assumed that the ACMS data used for comparison with the numerical simulations were for the case that the speed brakes were not operated. The results of these simulations are described below.

The numerical simulation for the case that assumed that the outboard and inboard elevators followed the ACMS outboard elevator surface angle time history was found to coincide with the aircraft motions at the time of the accident.

① Using raw ACMS elevator surface angle

The numerical simulation time history and the ACMS time history corresponded well until the first pitch up, but there were differences after that. In particular, there were large variations of θ in the numerical simulation and the values of θ were smaller than in the ACMS time history. As a result, the CAS and TAS in the numerical simulation were greater than in the ACMS data, and while the aircraft was in level flight in the ACMS data it was descending in the simulation.

The peak negative value of vertical acceleration (NzIRU) in the numerical simulation was virtually the same as in the ACMS data, but the peak positive value was smaller.

The positive peak values of vertical acceleration at the center of gravity (NzCG) coincided between the numerical simulation and the ACMS data. However, the phases of both NzIRU and NzCG were more advanced than in the ACMS time history.

② Using ACMS outboard elevator surface angle for both inboard and outboard elevators

With the exception of NzIRU and NzCG, the results of the numerical simulation corresponded well with the ACMS time history. In particular, CAS, θ and altitude, which did not coincide with the ACMS time sequence after the first pitch up in the case ① above, also corresponded well.

The variations of both vertical accelerations NzIRU and NzCG were smaller compared with the above-mentioned case ①, but like case ① they were phase advanced compared to the ACMS data.

(See Figure D in Appendix 3.)

(3) Numerical simulation analysis of aircraft motion

Having confirmed that numerical simulation could reproduce the aircraft's motions, simulation was then used to analyze the effects of wind changes, elevator surface angle and the speed brake control on the aircraft's motion.

As described in (2)② above, the simulation corresponded well with ACMS data if ACMS outboard elevator position data was used for the position of both inboard and outboard elevators. Consequently, in the subsequent aircraft motion analysis, the ACMS outboard elevator time history used for the movement of both inboard and outboard elevators was used as the control input to reproduce flight conditions immediately before and after the accident.

In addition, while there was no record of speed brake lever operation in the DFDR or ACMS data, because the flight crew stated that the captain deployed the speed brake lever, the case was also examined in which the estimated time of operating the speed brakes was used as control input to reproduce the flight conditions around the time of the accident.

The results of these analyses are as follows.

① The effect of wind speed change

A simulation was conducted assuming no wind, TAS almost constant, and CAS gradually increasing with the increase of atmospheric pressure during descent. Although movement of the elevators resulted in pitch motion, except for the first pitch up, the variations of θ, aircraft pitch rate q, AOA, and

NzIRU and NzCG were virtually the same magnitude as for the case of the same wind existing as at around the time of the accident.

The change in θ during the first pitch up was less than half, and this difference remained in the central value of θ during the pitch motion and in the difference of θ after the pitch motions had converged. This difference of θ resulted in a difference in descent rate, and because the first pitch up was smaller, the peak positive value of vertical acceleration at that time was also smaller.

Consequently, the wind velocity change which the aircraft encountered around the time the accident produced a rapid change in airspeed and was with part of the first pitch up.

In addition, the difference between simulation result with vertical wind data and without vertical wind data that was derived from ACMS data as described in 2.11.2, was very small.

(See Figure E in Appendix 3.)

② The effect of elevator control

a. Case with elevators fixed at the position before the windshear encounter with the same wind condition as at around the time of the accident.

(Result)

If the elevators were assumed fixed at the time the strong windshear was encountered at 1057:36, thereafter a simple increase of θ and decrease of descent rate occurred. Finally θ became 5°, the aircraft climbed and the final altitude value at the end of the simulated time period was 300ft higher than for the case where the elevators were controlled as during the accident. Meanwhile, the airspeed showed almost the same variations (difference in CAS was less than 5kt) as the controlled elevator case.

The pitch motions during the simulation time period were markedly smaller than for the controlled elevator case, resulting in an NzCG of +0.86 – +1.38G.

In conclusion, even if the elevators had not been used to try to suppress the rapid speed increase caused by the windshear, the maximum airspeed value would have been the same as for case where the elevators had been used (285kt CAS), and the large pitch change and accompanying vertical acceleration would not have occurred. However, in that case the aircraft would not have continued to descend steadily but would have begun to climb.

(See Figure F in Appendix 3.)

b. Case where after pitch up control is applied to suppress the rapid speed increase caused by windshear, pitch down control is applied to return θ to its original value, and the elevators are fixed for five seconds, then returned to its original value.

(Result)

After θ reached a maximum of around 7°, it was stabilized at around 3° by the application of pitch down control. The airspeed and altitude showed almost the same variations as for the case where the elevators were controlled as during the accident. The pitch down after the first pitch up was slower than during the accident, the overshoot of θ was smaller, and pitch attitude was almost constant two seconds after the elevators were fixed. Although NzCG reached +1.76G during the pitch up, the minimum value during the pitch down was +0.59G, and thereafter it was +0.91–+1.23G.

In conclusion, after the application of pitch up control to suppress the rapid speed increase due to windshear, when slower pitch down control was applied to return the pitch attitude to its original value, after which the elevators were fixed, the pitch attitude returned to its original value with almost no oscillatory pitch motions occurring. Further, the change in vertical acceleration after the pitch down was less than 40% than during the accident, and no significant downward acceleration occurred.

(See Figure G in Appendix 3.)

③ The effect of speed brake control

A simulation was conducted assuming that after encountering strong windshear, the speed brakes are deployed to the maximum position (spoiler panels 3, 4, 9, and 10 at 45°, spoiler panels 5–8 at 20°) during flight. (Since the speed brake data is recorded on DFDR at 1Hz (once a second), the time of spoiler use was around 2 second, a period for which it is thought possible that spoiler movement would not be recorded by the DFDR.)

(Result)

As a result of speed brake deployment, there was a change in pitch rate followed slightly later by increases of θ, AOA, and NzCG. Compared with the case where the speed brakes were not operated, the peak value of θ was around 3° greater, and NzCG increased by around 0.3G. Further, the airspeed decrease occurred slightly earlier.

(See Figure H in Appendix 3)

2.11.8 Vertical acceleration in the cockpit and aft cabin

The vertical accelerations experienced at the cockpit, the seat positions where serious injuries occurred, and the aft lavatories were investigated. The method of computation and results are presented in Appendix 4.

The vertical acceleration in the cockpit was computed as a maximum of +1.7G at the first pitch up, and a minimum of +0.2G at the first pitch down.

At the seat position of the row of 47, the maximum vertical acceleration was +2.0G and the minimum –0.6G.

In the aft lavatory, the maximum vertical acceleration during the first pitch up was +2.1G the minimum –0.6G at the first pitch down.

Vertical acceleration experienced was strongly affected by position along the length of the aircraft, and the difference between maximum and minimum became greater the further aft.

2.11.9 Flight Simulator Tests

A flight simulator was used to reproduce the flight at the time of the accident. Simulations were made of the approach to M_{MO} and stick shaker activation and recovery.

The Boeing 747-400 simulator used for the tests was a first rank flight simulation device equipped with sophisticated visual and motion systems, and had been approved as a Phase 3 device, the highest degree of fidelity, by the Japan Civil Aviation Bureau of the Ministry of Land, Infrastructure and Transport.

Although the accident aircraft was a Boeing 747-400D, because there was no flight simulator for this aircraft model in Japan, a Boeing 747-400 flight simulator was used for the tests. The external difference between these aircraft models is the presence or absence of winglets installed on the wing tips, but there were no differences that would affect the flight simulation test results.

According to the flight simulator's operator, the flight simulator had the following characteristics:

- High altitude flight characteristics

At low altitude the operational performance is virtually the same as the real aircraft, with the necessary simulation fidelity for training, but the simulation fidelity at high altitude is not the same as at low altitude.

- FCC equipped on the flight simulator
  Because the FCC differs from that installed on the real aircraft, it is possible that the behavior is accurate in at least FLCH mode.
- Wind simulation
  Complex wind conditions are not set in normal training.
- Manual override force
  When performing an autopilot manual override with one autopilot system engaged, the override force on a real aircraft was measured at 27lb, but its value was smaller in the simulator.

However, the purpose of the simulator test flights was not to obtain precise quantitative data, but to reproduce the flight at the time of the accident and also to qualitatively understand the flight conditions when different maneuvers are attempted in response to a sudden airspeed increased.

(1) The flight parameters for the simulator test flight

Twenty-six wind values for the descent during which the accident occurred from around 39,800ft to around 38,800ft were selected from the ACMS data and programmed into the simulation.

The aircraft parameters were set to the same values as at the time of the accident. Further, since the aircraft had started to descend from the FMC-computed top of descent point in VNAV/PTH mode, in order to simulate the descent conditions during the accident wind parameters considered to be normally used were taken from the wind data recorded in the flight log book which had being used by the aircraft's flight crew and input into the FMC, and the top of descent position was computed.

(2) Simulator test flight results

Since as described above it is thought that the simulation fidelity of the JAL flight simulator at high altitude is not as great as at low altitude, the results of the simulator flight tests cannot be considered to correspond directly to the motions of the real aircraft, but the characteristics of the aircraft motions etc. were largely simulated.

The results of the simulator flight tests are summarized as follows.

① Reproduction of the flight at the time of the accident

During autopilot-controlled descent in VNAV/PTH mode, airspeed changes and a sudden increase over Mach 0.91, and a trend indication predicting a further speed increase beyond M_{MO} were reproduced on PFD SPD/MACH.

After performing a speed intervention setting Mach 0.80, the autopilot was manually overridden by pulling back the control column to prevent further speed increase, and this resulted in the stick shaker operating. The autopilot was then disengaged, the nose lowered and control applied to stabilize the pitch attitude. Pitch attitude was largely stabilized after two or three cycles of oscillation. This series of aircraft motions largely replicated the aspects of the flight at the time of the accident.

However, the condition in which the stick shaker operated while the autopilot was engaged was reproduced by pulling the control column back so as to make the pitch angle same value as that of recorded in the DFDR. This was because the stick shaker could not be made to operate by any other method such as only use of speed brakes etc. However, it could not determined based solely on the simulated flight test whether during the accident flight the condition in which the stick shaker operated was caused by the pilot actually pulling back on the control column.

② Recovery from the condition close to M_{MO}

As a result of the programmed wind data being selected from the ACMS data during descent at the time of the accident, the simulator flight was able to reproduce the airspeed change and the sudden increase in airspeed over Mach 0.91, and also the trend indication predicting a further airspeed increase beyond M_{MO}. Therefore, simulated flight tests were carried out of each type of method to recover from this condition.

a. Recovery using autopilot

Tests were conducted using each type of autopilot mode, but the conditions of the sudden speed increase were the same for each case.

(a) Speed intervention only

A speed intervention of Mach 0.80 was made. The speed exceeded Mach 0.91 slightly, but did not exceed M_{MO}, and thereafter it reduced slowly towards Mach 0.80. Because of the rapid increase in Mach number, a pitch increase of around 2° and an increase in vertical acceleration were observed.

(b) ALT HOLD mode selected

ALT HOLD mode was selected at the time Mach number suddenly increased (Mach 0.88–0.89). The speed exceeded Mach 0.91 slightly, and thereafter decreased slowly. An increase in vertical acceleration was observed at the time of the rapid Mach number increase.

(c) V/S mode selected

In the first test for this case, V/S mode was selected and after making a Mach 0.8 speed intervention, the rate of climb/descent was set to 0ft/min. The Mach number showed the same tendency as cases (a) and (b) above, but afterward decreased yet more slowly.

In the second test for this case, V/S mode was selected, then the rate of climb was set to +1,000ft/min. In this case, the initial decrease in Mach number was not significantly different from the case of setting vertical speed to 0ft/min. The subsequent decrease in Mach number was more rapid than in the case of setting the vertical speed to 0ft/min, but was almost the same as in the ALT HOLD mode case.

(d) FLCH mode selected

A Mach 0.8 speed intervention was made followed by selecting FLCH mode. In this case, the pitch change was rapid and there was a large change in vertical acceleration, and the Mach number decreased quickly.

(e) Speed brakes used

In the first test for this case, the speed brakes were abruptly selected to the maximum usable in flight. In this case, Mach number reached a maximum of around 0.905 but after that decreased gradually.

In the second test for this case, the speed brakes were smoothly selected to the maximum usable in flight. In this case, the indicated Mach number reached a maximum of around 0.91, but the later Mach number decrease was not significant different from first the case. However, the pitch change and increase in vertical acceleration were greater for the case that the speed brakes were selected abruptly.

In the third test for this case, a Mach 0.80 speed intervention was made followed by abrupt use of the speed brakes. The decrease of Mach number in this case was the most rapid of all the speed brake use cases.

b. Reducing speed by manual control after disengaging autopilot

In the first test for this case, the control column was pulled back rapidly to raise the nose. A large pitch up and a moderately large vertical acceleration resulted and there were one or two pitch oscillations before pitch became stable. This could not prevent the rapid Mach number increase, but because the aircraft started to climb, the subsequent Mach number decrease was rapid.

In the second test for this case, the control column was pulled back smoothly. In this case, the pitch up was small, there was no tendency for pitch oscillation, and the changes in vertical acceleration and decrease in Mach number were slow.

③ Recovery from stick shaker activation

After performing a Mach 0.8 speed intervention, the stick shaker was caused to operate by manually overriding the autopilot, and then recovery from the stick shaker condition was made attempted.

a. Recovery using autopilot

The aircraft pitched up as a result of the control column being pulled back, vertical acceleration increased, and Mach number decreased. After stopping manual override, the increased pitch decreased, and there was no oscillatory tendency.

b. Manual recovery after disconnecting autopilot following stick shaker activation

If the control column was moved quickly forward to reduce the pitch, the control column was moved forward of the central neutral position, the pitch angle reduced rapidly and overshot, and there were two up and down movements until it settled. This was sufficient to induce negative vertical acceleration.

If the control column movement was moved slowly to reduce pitch slowly and stopped at around the neutral position, the pitch angle returned slowly and the change in vertical acceleration was also gentle.

The speed intervention was made at the same time as was thought to have been the case in the accident but the decrease in Mach number as a result of the intervention control was extremely slow. Further, although various autopilot modes were selected to arrest the increase in Mach number, the decrease in Mach number was again slow. Also, quite large amount of control column movement were required for the pilot so as to make pitch angle the same value and the same timing as recorded by the DFDR to simulate the aircraft's longitudinal motion.

2.12 Other Information

2.12.1 Descriptions in documents related to V_{MO}/M_{MO}

(1) AOM

JAL revised the descriptions for 'Maximum Operating Limit Speed (V_{MO}/M_{MO})' in the 'Operating Limitation' section of the Boeing 747-400 AOM on August 29, 2001 by adding the word 'intentionally' as shown in the following.

- Maximum Operating Limit Speed V_{MO}/M_{MO} shall not be *intentionally* exceeded during any flight phase.

(2) OPERATIONS INFORMATION bulletin

On March 16, 1998, JAL issued an 'OPERATIONS INFORMATION' bulletin with the title 'Dealing with Overspeed (V_{MO}/M_{MO})'. This bulletin described measures to deal with overspeed or a potential overspeed, and also the philosophy of V_{MO}/M_{MO}. The following is a summary of the main points of the OPERATIONS INFORMATION.

Although there may be slight differences depending on the speed and degree of approaching V_{MO}/M_{MO}, the flight phase and the mode in use, if it is judged that Automatic Flight System may not be able to control the aircraft's speed due to rapid wind changes etc. despite taking corrective action, it is finally necessary to control the aircraft by disengaging the autopilot and manually overriding or disconnecting the Autothrottle. The Automatic Flight System's overspeed protection also has a mode that functions when V_{MO}/M_{MO} is exceeded to some extent, and is not designed to always prevent V_{MO}/M_{MO} from being exceeded. Further, pilots are once again reminded that the Automatic Flight System is not designed to always control the aircraft's speed according to the pilot's intention no matter what external disturbance might occur. However, while V_{MO}/M_{MO} is a speed that must not be exceeded intentionally in operation, it is not necessary to make fast and hurried control actions if the speed is exceeded momentarily.

1. Measures to deal with excess of V_{MO}/M_{MO} or potential excess of V_{MO}/M_{MO}

   During flight, it is possible for speed to approach V_{MO}/M_{MO} when the headwind increases due to a change in the wind at heavy weights, or if the tailwind decreases. If these conditions are anticipated, it is essential not to stick to ECON speed but to operate at an appropriate speed with a margin for V_{MO}/M_{MO} in advance.

   In other words, it is important to monitor speed carefully and if there is a risk of exceeding V_{MO}/M_{MO}, to use VNAV speed intervention, FLCH mode early, and to prevent V_{MO}/M_{MO} from being exceeded by employing speed brakes etc. depending on the conditions.

However, if there is no time to follow the above actions or if speed continues to approach V_{MO}/M_{MO} even if action is taken, or if V_{MO}/M_{MO} has already been exceeded, in addition to disengaging the autopilot and disconnecting the Autothrottle the following actions can be considered depending on flight phase:

(Descent): First confirm that thrust is idle, and pitch up smoothly. Also, use speed brakes if necessary.

When the autopilot is disengaged or when pitching up, take due care to avoid abrupt attitude changes.

Further, when using speed brakes, in addition to being careful of pitch attitude changes, it is necessary to use care to avoid overspeed again on retraction.

2. Philosophy of V_{MO}/M_{MO}

V_{MO}/M_{MO} is specified as an operating limit in airplane operation manual, and is "a limit that the flight crews shall not control or operate the aircraft to exceed in operation".

On the other hand, airspeed limits in the civil airworthiness regulations are stipulated as follows:

> "except in the case that a higher speed is approved for flight test or flight training, a maximum operating limit speed shall not be intentionally exceeded regardless of flight condition"
>
> "V_{MO}/M_{MO} is specified as a speed below the design cruising speed Vc/Mc, and is also set to be sufficiently smaller than maximum speeds such as the design emergency descent speed Vd/Md etc, and must be established such that there is almost no possibility of inadvertently exceeding these latter speeds in operation."

Therefore, this means "it is not permitted to exceed V_{MO}/M_{MO} intentionally, but unavoidable momentary excess due to sudden wind changes is within permissible design limits". Therefore, it is appears that V_{MO}/M_{MO} will be exceeded unavoidably, or if V_{MO}/M_{MO} has been exceeded, it is possible take normal actions without undue haste to reduce speed safely to below V_{MO}/M_{MO} without reaching to Vd/Md, and dangerous conditions can be avoided. That is, there is no need for especially rapid control if

V_{MO}/M_{MO} is exceeded.

(However, it is necessary to record excess in the log book entry.)

3. Explanation of Systems

A) Overspeed Protection

"When the Automatic Flight System is being used, it is Boeing operational philosophy for this protection that the pilot should always monitor the flight path and take appropriate action in the event of deviations such as overspeed even if autopilot and Autothrottle speed protection is equipped."

B) Airspeed Filter

In order to control the aircraft smoothly in turbulent flight, the airspeed used by the autopilot speed control is data from the air data computer filtered to remove noise contained in the speed data. Consequently, if a large, rapid change of aircraft speed occurs due to wind shear etc., the airspeed used internally by the FCC may deviate slightly and be delayed with respect to the indicated airspeed.

C) G-Control

The autopilot controls the aircraft such that changes in G on the aircraft are below a certain value. Speed Correction Control also operates within this limit and is not designed to always control the aircraft's according to the pilot's intention.

D) Use of Speed Brake during Descent

When using a mode in which airspeed is controlled by pitch, it is necessary to use caution as there may be cases where a desired speed reduction cannot be obtained as a result being unable to achieve sufficient pitch up even if speed brakes are used.

2.12.2 Procedures when Encountering Windshear

The "Windshear Encounter" section of the Non-Normal Maneuvers part of JAL's AOM contains the description "if windshear is encountered in flight, carry out windshear escape maneuver procedures." There is also a warning in the Windshear Escape Maneuver, "In the case of severe windshear, it is possible that the performance capability of the AFDS will be exceeded. If necessary, the PF shall disengage the autopilot and disconnect the Autothrottle, and fly the aircraft manually".

2.12.3 Descriptions relating to Auto Flight Operation in JAL Manuals

The following are extracts of descriptions that appear in the section "Supplement

2-1: Flight Preparation and Execution, III Flight Execution, III-1 General, 5. Auto Flight Operation" of the Operations Manual Supplement to JAL's Operations Manual revision of November, 2001.

(omitted)

If it is judged that use of the Auto Flight System is not appropriate, or if the operating situation is different from that intended by the flight crew, it is necessary to promptly take appropriate measures such as changing mode, ceasing use etc.

(1) (omitted)

"The autopilot shall not be manually overridden during flight under autopilot control. Also, the autopilot shall not be disconnected while force is being applied to the control column."

(omitted)

JAL's Operations News (for 747-400 crew, Dec 14, 2001) "Bad effects of autopilot manual override", contained the following explanation of a revision of part of OM:

"It has been clarified that 'the autopilot shall not be manually overridden during flight under autopilot control' and that 'the autopilot shall not be disconnected while force is being applied to the control column'. It is also written that if operation differs from the pilot's intention, select a more accurate mode, revert to basic mode, or even disconnect the autopilot by the disengage switch. Further, it is described that if the autopilot is overridden manually, in addition to the situation becoming as described below, if the autopilot should happen to be disconnected while force is being applied to the control column etc. there is the risk of unexpected aircraft motions."

1. Override Pitch Axis with Single Channel Engaged

A. Override of Pitch Axis (autopilot NOT disengaged)

If force is applied to the control column while the autopilot is engaged, the elevators will operate according to the motion of the column. A few seconds later, the stabilizer will start to move in the opposite direction to the elevators by autopilot command, so the effect of the manual override will not be obtained. Further, if force is applied opposite to the stabilizer trim, control column cutoff will operate and the stabilizer will stop moving. After that, the pitch axis will be controlled by operation of the elevators.

(omitted)

2.12.4 Flight Simulator Training

(1) High Altitude Flight Training

Before the accident, JAL had conducted training in manual flight as part of its “In-flight Maneuvers” flight experience training for the Boeing 747-400. In the training, a turn is entered manually during high speed, high altitude flight and the bank angle steepened, then when high-speed buffet occurs, the aircraft is recovered to wings level. JAL captains and first officers were scheduled to receive this training during mid basic month periodic training, and candidate first officers received this training during the simulator training part of the initial first officer training course.

Following an accident that occurred to a McDonnell Douglas MD-11 airplane, JA8580, on June 8, 1997 in which PIO (Note 14) resulted after a windshear encounter, based on a proposal to adopt training to prevent recurrence of the accident and to train crews to properly respond to such situations, JAL had taken measures such as implementing a more realistic training environment in MD-11 Advanced Training by allowing pilots to experience the autopilot response to overspeed and adding turbulence mode to the high altitude characteristics training.

However, as it was confirmed that the characteristic of autopilot and the longitudinal stability of 747-400 was different from MD- 11, there was no training established for the Boeing 747-400 to allow crews to experience control characteristics in high altitude flight such as a rapid increase in airspeed following windshear encounter resulting in potentially exceeding V_{MO}/M_{MO}, or to switch to manual flight and decease speed after exceeding V_{MO}/M_{MO},

(2) Stall Training

The following is a summary of information in the JAL Pilot Flight Training about control in the case of an approach to stall with the autopilot engaged.

> In the event of an approach to stall with the autopilot engaged with, apply limit thrust and attempt to return to normal speed. At high altitude, it may be necessary descend a little to recover to maneuvering speed. If the autopilot response is not sufficient, it should be disengaged.

(Note 14): “PIO” (Pilot-Involved Oscillation) is a term used to refer to an oscillatory type of aircraft motion, if the Pilot–Vehicle System instability takes the form of an oscillation when the aircraft including the flight control system and the dynamics of the pilot combine to produce an unstable PVS.

2.12.5 JAL First Officer Training

The first officer had satisfied the first officer qualification requirements prescribed in the JAL OM.

According to the JAL Qualification Manual Bylaws, which are subordinate regulations to the Qualification Manual, in order to reinforce training, newly appointed first officers immediately undergo 'Proficiency Stage' training, distinct from their 'training' prior to first officer appointment, consisting of flying PF duty for 15 flights on flight routes under a supervisory captain. The captain of the accident flight was a flight instructor in the Department of Operations and Aircrew Training, and was qualified as a supervisory captain.

The pilot of the accident flight, who was qualified as a first officer, was to take over first officer duties on a series of scheduled flights that day, and it was planned that he assume first officer duties on flight 543 (Haneda–Hakodate) scheduled after the accident flight.

2.12.6 JAL Regulations on Fastening Seatbelts

The following are prescribed in the JAL OM.

9-3-3 Seatbelt Sign and Use of Seatbelts by Passengers

1. The PIC (Note 15) shall turn on the seatbelt signs in the following cases. If the seatbelt signs are inoperative, other means of enforcement shall be used.
   (1) During movement on the ground.
   (2) During takeoff and landing.
      Note: In principle, the PIC shall turn on the seatbelt signs for landing after notifying the cabin attendants of reaching 10,000ft.
   (3) During flight in turbulence and when turbulence is expected.
   (4) At other times as judged necessary.
2. When the seatbelt signs are on in flight (during the period from takeoff to landing), cabin announcements shall be made to ensure passengers fasten seatbelts. If the seatbelt signs are on for an extended period, the cabin announcements shall be repeated at appropriate intervals to ensure compliance.

Also, even when the seatbelt signs are off, cabin announcements shall be made to encourage use of seatbelts while seated.

(Note 15): "PIC" means the appointed crewmember (captain) who has ultimate responsibility for the operation and safety of the aircraft.

2.12.7 JAL regulations regarding notification of the occurrence of injury and administration of first aid

(Excerpt)

The following are prescribed in the JAL OM.

9-3-8 Measures on the occurrence of Illness and Death during Flight

1. Illness (Injury, attack of disease, etc.)

(1) A senior cabin attendant shall immediately the inform PIC.

(2) the PIC shall request the assistance of a doctor or nurse on board, and shall take appropriate action in accordance with their advice.

(3) If the assistance of (2) above is not available:

a. Cabin attendants shall administer the prescribed first aid treatment.

b. The PIC shall communicate the passenger's condition to relevant ground facilities and request medical advice, etc.

(4) The PIC shall make changes to altitude, route, etc. as necessary and in urgent cases, make an emergency landing.

Also, the PIC shall request relevant ground facilities to order ambulances as necessary.

3 ANALYSIS

3.1 Air Crew Certificates and Medical Certificates

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

3.2 Certificate of Airworthiness

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

As the result of investigation of the aircraft after the accident, it is considered that there was no abnormality in the aircraft's flight control system or autopilot.

3.3 Weather Conditions

It is estimated that the weather conditions in the vicinity of and at around the altitude of the descending aircraft during the period of time the accident occurred were as follows:

(1) The influence of convective cloud

As described in 2.6.1, on October 21, 2002, there was a low pressure system accompanied by a front extending offshore of the Kii Peninsula which was developing while moving east-northeast. According to the 09:00 nephanalysis information chart shown in Figure 8, a convective cloud zone including cumulonimbus was stretching from offshore the Kii Peninsula and Tokai region to the vicinity of the Izu Islands.

However, as described in 2.11.1(1), since the aircraft was flying at around 39,000ft at the time the accident occurred, based on the CAPPI chart issued by Meteorological Agency's Nagoya Radar (Figure 9) it is estimated that it was flying more than 20,000ft above the tops of the convective clouds.

Moreover, the flight crew stated that there was nothing that could be considered as an echo on the weather radar in the vicinity of the turbulent area during the descent, and that at around 39,000ft there were stratus-type clouds, not cumulus type.

Considering the above, it is estimated that the aircraft was not directly influenced by convective cloud at the time the accident occurred.

(2) Windshear

① Influence of subtropical jetstream and underlying trough

As described in 2.11.1(2), the tip of a subtropical jetstream was proceeding east along the south shore of the island of Honshu, and around the time that it passed through the location at which the accident occurred between 09:00 and 21:00 on October 21, it is estimated that wind strengthened and that the altitude of the maximum wind speed area became lower. Further, as described in 2.11.1(3), there was a trough below the subtropical jetstream which at 15:00 on October 21 had developed to an altitude of 200hPa and was west of the accident location. Therefore, as described in 2.11.1(5)②c, it is estimated that there was an updraft on the front face of the trough in the vicinity of the location of the accident, and that a lower layer air mass with a small southerly prevailing wind component was being transported up to around 200hPa (an altitude of around 39,000ft).

② Vertical Shear

As described in 2.11.1(4), the vertical shear around the altitude at which the accident occurred was computed using the aerological observation data for Hamamatsu, the aerological observation point closest to the location of the accident. The vertical shear at 09:00 on October 21 was slight at around 5kt/1,000ft, and at 21:00 on October 21 it was around 8kt/1,000ft.

However, the windshear computed from ACMS data at around the altitude at which the accident occurred was a very large value of around 40kt/1,000ft. It is considered that such severe windshear occurred when the jetstream which was descending while moving east was obstructed by an airflow carrying the updraft on the front face of the underlying trough.

③ Rapid changes of wind at a single altitude

As described in 2.11.1(6), according to ACMS data, rapid wind changes were occurring at a single altitude. It is considered that this occurred due to Kelvin-Helmholtz instability in the atmosphere depending on the presence of vertical shear that resulted in localized atmospheric disturbance.

3.4 Strong Windshear Forecast

According to the aerological observation data for Hamamatsu at 09:00 on October 21, the observation point and time closest to the accident, the vertical shear around the altitude at which the accident occurred was computed as around 5kt/1,000ft, and from the observation data at 21:00 it was computed as around 8kt/1,000ft. On the other hand, an extremely strong vertical wind shear of around 40kt/1,000ft was computed from the ACMS data after the accident. The aerological observation data was taken from the observation point and time closest to the accident, but weather data change over time, while on the other hand the weather data obtained from the ACMS are the actual data from the location and time of the accident. Also, from the ACMS data in Figure 14, the computed vertical windshear occurred in a narrow 500ft altitude band. It is therefore apparent that there is a considerable difference between the vertical windshear obtained from aerological observations and the ACMS data.

As described in 2.6.6, there was no forecast of CAT affecting the aircraft's round trip flight to Fukuoka in either the pre-flight weather briefing or from other weather information. Also, the flight crew stated that while they had received a report during the flight of moderate turbulence at 37,000ft over the FLUTE reporting point on the flight route, that was the only report of turbulence in spite of the fact that there should have been many other company scheduled flights operating during that time, they were flying at 41,000ft rather than the 37,000ft where the turbulence was reported, and furthermore they judged that since they would be starting to descend having passed the FLUTE point in the turbulence report, they would avoid turbulent region and altitude. From these facts, it is considered that a strong windshear encounter during descent could not have been predicted.

3.5 The flight situation until just after the accident

Based on the DFDR recording, ACMS recording, CVR recording and ATC communication transcripts, the flight situation from when the aircraft started to descend from its cruising altitude of FL410 at around 30nm east of FLUTE until immediately after the accident occurred was as follows.

3.5.1 From the start of descent until Mach number approached Mmo

According to the statements of the flight crew, the first officer had assumed PF duties from take-off.

After taking off from Fukuoka Airport, the aircraft cruised at FL410 with virtually no buffeting encountered, at around 10:56:35, started to descend to FL160 at ECON speed from the FMC-computed TOD (around 30nm east of FLUTE).

At 10:57:18, the center autopilot of the three autopilots (left, center, right) was engaged, the N1 values of all four engines were stable at around idle, and the aircraft was descending at Mach 0.864 in VNAV/PTH mode with the descent path controlled by changing aircraft pitch.

At 10:57:19, when the aircraft was descending through around 39,800ft, the Mach number began to change and increase. It is estimated that this was the result of the wind computed from the DFDR and ACMS data shown in Appendix 2 beginning to change, and the aircraft starting to be affected by this wind change.

At 1057:26, at 39,600ft, the aircraft's speed increased to Mach 0.886.

At 1057:27, speed decreased to Mach0.879.

At 1057:28, the captain called "Speed, speed", calling the attention of the first officer who was the PF.

At 1057:29, at around 39,450ft, the autopilot descent mode changed from VNAV/PTH to VNAV/SPD. This is estimated to be the result of the first officer, having being advised of the speed increase by the captain, pushing the IAS/MACH selector on the MCP to reduce speed by making a speed intervention, thereby causing the autopilot descent mode to change. At that time, the aircraft's speed was Mach 0.866.

At 10:57:30, the aircraft's speed was Mach 0.865, and at 10:57:31, it reduced slightly to Mach 0.859.

At 10:57:33, as the speed reached Mach 0.867 and again showed a tendency to increase, the captain instructed the first officer to reduce the autopilot command speed by calling "Make an intervention to bring it back more".

At 10:57:34, the speed was Mach 0.865, and at 10:57:35, it was Mach 0.869.

At 10:57:36, the selected speed on the MCP changed to Mach 0.80. This is considered to be because, as stated by the flight crew, in addition to the captain instructing the first officer to make a speed intervention and reduce the command speed by making a speed intervention, he himself set the IAS/MACH selector. However, the Mach number again showed a tendency to increase to Mach 0.876.

3.5.2 From the time of approaching Mmo until immediately after the accident occurred

At 10:57:37, Mach number momentarily decreased to Mach 0.867. The vertical acceleration became +1.14G (+1.13G in the ACMS data), and it is estimated that autopilot was controlling the speed within the VNAV mode vertical acceleration limits.

At 10:57:38, the aircraft's speed was Mach 0.914, and vertical acceleration was +1.14G. (In the ACMS data, Mach was 0.912, and vertical acceleration was +1.16G.)

At 10:57:39, there was a large movement of the elevators in the nose up direction to an indicated +5.9°, vertical acceleration increased to +1.24G, and speed decreased to Mach 0.889. From the flight crew statements that there was a large pitch up and the stick shaker operated just after the speed brake lever was pulled, it is considered possible that the captain pulled back the speed brake lever at around this time.

At 10:57:40, the speed became Mach 0.903. At the same time, the CCP moved to +4.6° nose up, aircraft pitch angle increased from its negative value until that time to +2.5° nose up, and vertical acceleration attained +1.89G, which is beyond the VNAV mode vertical acceleration limit.

At 10:57:41, CCP began to return to nose down, but the aircraft's pitch angle was +6.4°, vertical acceleration reached +1.95G, and the stick shaker operated.

At 10:57:42, there was a large movement of CCP in the nose down direction (–9.6°), but the aircraft's pitch angle was +8.3°, vertical acceleration was +1.86G and the stick shaker operated. Further, the autopilot became disconnected. Since there is a time delay from the autopilot disconnecting until the event is recorded on the DFDR, it is considered possible that the autopilot actually became disconnected earlier than 10:57:42.

At 10:57:43, CCP moved to its peak nose-down position of –12.5 ˚, pitch angle was +5.2°, and vertical acceleration was –0.39G. Because at the same time the captain and the first officer called "You have control" and "I have control" to transfer PF duties, it is estimated that the captain took over control from the first officer at this time. However, as the Captain was in the position to lead the first officer under 'Proficiency Stage' training, and the aircraft immediately approached the speed of operating limit, it was thought possible that the Captain had a hand in controlling the aircraft before calling change of PF duty.

At 10:57:44, CCP moved to +2.3°, pitch angle was –1.5°, and vertical acceleration was –0.34G.

At 10:57:45–46, vertical acceleration exceeded +1.7G, and at 10:57:47, the stick shaker operated again. At 10:57:48, vertical acceleration was +0.66G, and at 10:57:50 it was +1.34G. At 1057:52, vertical acceleration became +0.79G, and there were no further large pitching motions.

3.6 Rapid Increase of Pitch and Subsequent Pitch Change

The rapid increase of pitch during the descent and subsequent pitch changes are estimated to have been the result of the following process from 3.6.1 to 3.6.3.

3.6.1 The rapid increase in airspeed and the autopilot's response

(1) Wind changes affecting the aircraft

During descent at Mach 0.865, at 10:57:26, the aircraft's speed increased to Mach 0.886 at around 39,600ft and at 10:57:31, it momentarily decreased slightly to Mach 0.859.

Then, at 10:57:38, the aircraft's speed was Mach 0.914, and approached the Mmo of Mach 0.92. (The speed in the ACMS data was Mach 0.912 at that time.)

Based on the wind computed from the ACMS data in Appendix 2, when the Mach number increased rapidly, the tailwind rapidly decreased resulting in a rapid increase in headwind from the aircraft's standpoint. During the 5-second period in which the aircraft's Mach number increased rapidly, the tailwind component dropped by nearly 30kt, and as a result it is estimated that airspeed (CAS) increased rapidly by around 20kt.

On the other hand, the change in vertical wind speed component remained less than ±8kt even at the time of the accident. This variation in vertical wind speed component resulted in a change of angle of attack of slightly less than ±1°, and it is estimated that this did not have a strong influence on the aircraft's motion.

Also, it is considered possible that the lateral shaking reported by cabin crew and passengers immediately before the severe up and down motion occurred was caused by encountering this wind shear.

(2) The autopilot's response

As described in 2.11.5(2), the autopilot's speed control authority in VNAV mode is limited to a vertical acceleration change of 0.15G in the speed area including speed protection region near Vmo/Mmo.

Vertical acceleration of up to +1.14G was recorded between the start of the descent to 10:57:38. During this time, a Mach 0.8 speed intervention was made using the MCP and the mode changed to VNAV/SPD; however, it is estimated that the autopilot controlled the speed within the 0.15G vertical acceleration limit for VNAV mode.

Mach number increased rapidly from 10:57:38.

At 10:57:39, vertical acceleration increased beyond the range of the autopilot VNAV mode vertical acceleration limit.

As described in section 2.11.5(7), though the speed used by the autopilot supplied by the ADC is filtered by the FMC while computing the VNAV pitch command and so did not increase rapidly to the same value as CAS, it is considered that the airspeed was approaching the maximum operating limitation speed, and had reached the speed range of Vmo/Mmo -11kt in which VNAV speed protection operates so that the maximum operating limitation speed is not exceeded. However, it is therefore thought that the autopilot was controlling the airspeed using pitch commands within the VNAV mode 0.15G incremental vertical acceleration limit in this speed range near Vmo/Mmo.

3.6.2 The increase in aircraft pitch

(1) The effect of speed brake operation

After Mach number increased rapidly to Mach 0.914 at 10:57:38, it was indicated as Mach 0.889 at 10:57:39. CCP increased to +1.2° nose up, the elevator surface angle became +5.9°, and vertical acceleration reached around +1.24G. (According to the ACMS data at that time, CCP increased rapidly to +5.1° from a value of +0.4° one second earlier, and the surface angle of the left inboard elevator had increased rapidly to +4.8° from +1.9° one second earlier.)

At 10:57:40, the aircraft's speed was Mach 0.903, CCP increased greatly to +4.6° nose up, pitch angle increased from its value up to that time of less than 0° to +2.5°, and the vertical acceleration increased rapidly to +1.89G. (According to the ACMS data at that same time, CCP was +3.3°, the surface angle of the left inboard elevator was +4.3°, and the pitch angle was +5.6°.)

According to the flight crews' statements, although the first officer was the Pilot Flying, the captain recognized the rapid increase in airspeed and pulled the speed brake lever back to reduce speed.

When the speed brake lever is pulled back, a nose-up pitching moment that results in the aircraft's nose rising is created generally, and there is also an effect of speed reduction due to increased drag. However, operating the speed brakes for only a short period of around 1–2 seconds has hardly any affect on airspeed and or altitude, but there is a momentary increase in vertical acceleration due to a small pitching motion.

As described in section 2.11.7(3)③, based on the numerical simulation of the effect of speed brake operation, pitch angle increased by around 3° and NzCG increased by around 0.3° compared with the case without use of speed brakes.

Further, as described in section 2.11.9(2)②a (e), even during the simulated flight tests, at the beginning the speed brake was used, an initial pitch upwas observed, but the speed reduction was slow.

There was no data in the DFDR and ACMS recordings regarding use of speed brakes, during that time; neither speed brake lever position nor spoiler surface movement due to speed brake operation. However, since the recording rate of the DFDR and ACMS is once per second, it is possible that speed brake operation for a very short period like one or two seconds will not be recorded, so it is considered possible that speed brakes were used for a very short period of time. Further, from cabin crew statements reporting "an unusual vibration and a noise like the earth rumbling" before the upset occurred, it is considered possible that the speed brakes were used at that time. But, it is thought possible that the sound that cabin crew heard was produced at the time when the aircraft encountered windshear.

A metallic clashing sound was recorded on the CVR at 10:57:45 just after the captain took over control at 10:57:43. The possibility was considered that the sound was made when the captain returned the speed brake lever to its original position. However, considering that if the speed brake had been used for the five seconds from the time of the rapid Mach number increase until around the time described above, then corresponding data would have been clearly recorded on the DFDR and ACMS, so it is thought that the metallic sound was not the sound of the speed brake lever being returned to its original position.

Further, according to paragraph 3.D of section 2.12.1(2), the JAL Operations Bulletin advised that a desired speed reduction may not be obtained when speed brakes are used in a mode in which speed in controlled by pitch such as VNAV/SPD mode.

Because it is thought that the deceleration effect of the speed brakes is gradual, even if the speed brakes were used for such a short period as to leave no recording on the DFDR and ACMS and had not been extended to maximum, it is thought that their effect on curbing the airspeed increase and reducing airspeed would have been slight. However, it is considered possible that they contributed to the increase in aircraft pitch angle from 10:57:39.

(2) The rapid airspeed increase and motion of the elevators

Based on the numerical simulation analysis of aircraft motion, it is estimated that a change of wind speed created a rapid change of airspeed, and was a one of the causes of the first pitch up motion. Further, the increase in pitch angle and the accompanying increase in vertical acceleration are thought to be connected with the motion of the elevators. That is, at around 10:57:34–36, after the Mach 0.80 speed intervention, it is estimated that autopilot attempted to control the airspeed within the VNAV mode 0.15G vertical acceleration limit.

At 10:57:39, when the airspeed increased, CCP increased to +1.2° nose up, the elevators moved to +5.9°, and vertical acceleration became around +1.24G. At 10:57:40, there was a large movement of CCP to +4.6° nose up, the aircraft pitch angle, which had been below 0° until that time, increased to +2.5, and there was a rapid increase in vertical acceleration to +1.89G. In this way, the vertical acceleration increased beyond the autopilot control authority limit.

According to the aircraft's manufacturer, the elevator angle used within the vertical acceleration limit in autopilot VNAV mode is around 3°. And, as described previously, the autopilot controls airspeed with pitch command using incremental G limit in VNAV mode so as not to exceed the maximum operating limitation speed. So it is thought that the surface angle deflection greater than this limit were not the result of the autopilot's pitch control.

As described in section 2.11.5(1), elevator movement by the autopilot is fed back to the control column. However, there was no sensor to distinguish pilot control inputs to the control column and consequently nor data. Therefore, it is impossible to identify whether the movement of the elevators was the result of autopilot or pilot control inputs to the control column. However, as described in section 2.11.5(3), if the pilot manually overrides the autopilot with one autopilot engaged for longer than 6 seconds, an autopilot caution is issued, but in the case of the accident, there was no recording of the caution on the DFDR etc., and no mention of such a caution in the flight crews' statements. From these facts, it is thought that pilots did not manually override the autopilot by the control column for more than 6 seconds. However, it could not be clearly established whether or not manual override was used.

3.6.3 Autopilot disengagement and the occurrence of pitch change by manual maneuvering

At 10:57:41, the stick shaker operated when the aircraft's speed was Mach 0.884 and pitch angle was +6.4°. As described in section 2.1.3(3), the conditions for stick shaker activation depend on the angle of attack measured by vanes, pitch rate, flap setting, Mach number, speed brake position and landing gear position. Consequently, it is thought that the stick shaker operated at that time due to the pitch angle and angle of attack rapidly increasing and exceeding the threshold values for stick shaker activation. At that time, the CCP and elevators started to move towards nose down. It is considered that the reason for this was that because the stick shaker operated, the first officer or the Captain lowered the nose to recover from the close to stall situation. Although the autopilot was recorded as engaged, it was disengaged almost at the same time and after that the aircraft's pitch was lowered, because the DFDR and ACMS recording rate for autopilot engagement and the disengagement is once per second, and there is more than 1 second of maximum time delay from the autopilot disconnecting until the event is recorded on the DFDR.

The autopilot disengaged at 10:57:42, but since there was no record of autopilot malfunction and the autopilot disconnect aural warning (siren), which sounds when autopilot is disengaged, was not recorded on the CVR recording, as described in section 2.11.5, it is considered that the autopilot was disengaged by a pilot pushing the autopilot disengage switch usually used to disengage the autopilot twice in quick succession. Regarding the autopilot disconnection, the first officer, who was PF at the time, stated that he did not know whether or not the captain had intentionally disconnected the autopilot, but he himself had not. Further, the captain stated that he did not clearly remember but either he disconnected the autopilot or it disconnected itself. It is therefore considered that when the stick shaker operated, the captain disengaged the autopilot to respond to the situation quickly.

At the same time, there was a large movement of the CCP in the nose down direction. Since the stick shaker operated at 10:57:41, it is considered that this was the result of the autopilot being disengaged and the nose being lowered manually to recover from the near stall condition.

At 10:57:43, the captain called “I have control” and took over control from the first officer. The CCP reached its maximum nose-down value of –12.5° and a vertical acceleration of –0.39G was recorded.

At 10:57:44, the CCP returned to a positive value (aircraft nose up), and at 10:57:47, the stick shaker operated again. However, because the first pitch down after the autopilot was disengaged had been large, a large nose up control input was made to restrain this motion leading to a subsequent pitch change. It is therefore considered that a subsequent pitch change. After the aircraft’s airspeed (CAS/Mach number) increased rapidly when it encountered the strong windshear, the prominent pitching motions after the autopilot was disengaged were the result of manual control. Pitch motion had first arisen due to the strong windshear encounter, but from the numerical simulation analysis results, it is considered that the subsequent large pitch variations after the autopilot disengagement were mainly the result of elevator motion, and the contribution of atmospheric disturbance is thought to have been small.

3.7 Factors related to Manual Control

When the aircraft’s airspeed increased rapidly, because the stick shaker operated after pitch angle and vertical acceleration increased rapidly, it is estimated that the autopilot was disengaged by a pilot and a rapid pitch down was made. After that, the pilot attempted to control the pitch response by operating control column, and there were around 2 cycles of large pitch change which were stable and convergent. The following are thought to have contributed to this control behavior.

(1) No expectation of the rapid airspeed increase

The first officer, who was PF at the start of the descent, stated that the trend indicator on the airspeed indicator grew rapidly and became very large, so he quickly made a speed intervention to prevent acceleration. He stated that as the speed did not decrease immediately, the captain pulled the speed brakes, but even then the speed did not decrease.

As described in section 3.6.1(1), the rapid increase in airspeed is estimated to have resulted from a decrease of the tailwind component, which reduced by around 30kt during the five second period immediately prior to the accident, causing the airspeed (CAS) to increase rapidly by around 20kt. As described in section 2.11.9(2)①, during the reproduction of the flight at the time of the accident using a flight simulator, changes in Mach number, a rapid increase over Mach 0.91 and the trend indicator predicting a Mach number increase beyond Mmo were shown on the PFD airspeed/mach display.

As the captain stated that he had not thought that turbulence would be encountered during the descent, it is considered that he and the other members of the flight crew had not anticipated a rapid increase in airspeed due to windshear.

It is considered that the flight crew, who were not expecting turbulence, suddenly encountered severe turbulence and saw a large jump in airspeed and an extremely large acceleration, an extremely large growth of the airspeed indicator's trend indicator and a rapid Mach number increase trend well beyond Mmo, and entered a mental state similar to that in an emergency condition. Further, although they made a speed intervention by operating the MCP, they did not see an immediate effect of the autopilot speed control and judged that the autopilot was unable to cope with rapid speed increase.

These factors are thought to have influenced the flight crew's manual control responses.

(2) The selection of descent speed

During the descent in which the accident occurred, the aircraft was flying at the ECON speed of around Mach 0.865. As described in section 2.12.1(2), JAL's Operation Information bulletin stated that "During flight, it is possible for speed to approach V_{MO}/M_{MO} when the headwind increases due to a change in the wind at heavy weights, or if the tailwind decreases. If these conditions are anticipated, it is essential not to stick to ECON speed but to operate at an appropriate speed with a margin for V_{MO}/M_{MO} in advance."

It is thought that because the flight crew had not anticipated a windshear encounter in which Mach number would rapidly increase and appear to be going to exceed Mmo, they did not have any doubts about using a high ECON speed as normally used.

(3) Manual Handling Characteristics at High Altitude

When applying a force to the control column to move the elevators and change the aircraft's pitch, the pitch change gives rise to a vertical acceleration. Air density is low at high altitude, and the damping of the aircraft's motions by aerodynamic forces is small. Therefore, when the elevators are moved to change the aircraft's pitch, the amount of pitch change often becomes larger at high altitude than at low altitude. Consequently, there are high possibilities that a larger vertical acceleration results.

It is considered that when the autopilot was disengaged at the time of the accident while the flight crew was dealing with sudden airspeed increase and consecutive operation of the stick shaker, the flight crew could not change smoothly to manual control because the flight crew did not expect the situation where disengaging the autopilot was needed as described in (1) of this section and because the aircraft was in the condition where the flight data on pitch direction were changing, and as a result there was a large rapid movement of the control column resulting in rapid operation of the elevators. Since the aerodynamic force damping of the aircraft's pitch motion was low at the high altitude, it is estimated that large pitch changes and large vertical acceleration changes occurred simultaneously. When maneuvering manually at high altitude, it is necessary to control pitch angle by using little by little, slow and smooth control inputs.

(4) The assumption of control by the captain

According to the captain's statement, he took over control and then since he felt a pitch up tendency and the stick shaker operated, he applied pitch down control.

Based on DFDR and CVR recordings, it is estimated that the captain took over control in the middle of the pitch down maneuver, and at that time, it is thought that the control column was moving. It is therefore considered that it was not a situation in which a smooth transfer of control was possible, and it is possible that this was a factor that caused the large pitch down.

3.8 DFDR and ACMS Data

As described in section 2.11.7 paragraphs (1) and (2), the following inconsistencies were found with the DFDR and ACMS data.

(1) The flight crew including the captain mentioned in their statements use of

the speed brakes or the possibility that the speed brakes were used, but there were no recordings indicating movement of the speed brake lever or spoilers.

(2) During a time in which there were no stabilizer control signals, the recordings of stabilizer motion show the stabilizer moving rapidly to an extent thought not to be possible by the stabilizer actuation mechanism.

(3) Nonlinearity in the outboard elevator surface angle data, and in the motion of the inboard elevators, a greater difference between the angles of the inboard and outboard surfaces greater than that which would result from the control mechanism.

(4) A difference between the numerical simulation result and ACMS time histories is found when ACMS data are used for the time history of elevator surface angle in the numerical simulation. However, when the ACMS time history for the outboard elevators is used for the movement for inboard and outboard elevators, the numerical simulation result coincides well with the aircraft's motion at the time of the accident.

Regarding (1) above, if the flight crews' statements are correct, it is considered possible that the speed brakes were operated for such a short period that the DFDR data recording rate was not able to capture their operation, but the causes could not be clarified.

Regarding (2), thought because the recordings were not of actual stabilizer motion but of motions resulting from elastic deformation.

Regarding (3) and (4), it is thought because that sampling rate of elevator angle in the ACMS recordings etc are limited, and the time alignment between CCP data and elevator angle recorded was lost.

3.9 Actions when it appears Mmo may be exceeded, and Flight Simulator Training

(1) Up until July, 2001, before the accident occurred, JAL's AOM for the B747-400 stated regarding Mmo that "Maximum Operating Limit Speed Vmo/Mmo shall not be exceeded in any flight phase". In August, 2001, this was revised to "shall not intentionally be exceeded in any flight phase".

JAL also revised the "Response for Overspeed (Vmo/Mmo)" in its "Operations Information No. 400-184 (Dated: Nov. 10, 2003)" (Appendix 6). However, as described in section 2.12.1(1), the "Response for Overspeed (Vmo/Mmo)" (March 16, 1998) in the edition of "Operations Information" prior to the revision described corrective actions when it appears that Vmo/Mmo will be exceeded and in the case that Vmo/Mmo is exceeded, and also the philosophy of Vmo/Mmo, and this had been distributed to flight crews. These descriptions contained information that if Vmo/Mmo is approached despite having taken corrective actions, or if Vmo/Mmo has already been exceeded, the autopilot should be disengaged, to pitch up smoothly if the aircraft is descending, and that speed brakes should be used as necessary. Further it described that care should be taken to avoid rapid changes in the aircraft's attitude when disengaging the autopilot or pitching up.

As described in section 2.12.2, the aircraft's AOM stated that if severe wind shear is encountered, if it is suspected that the flight conditions exceed the capability of the autopilot, if necessary the pilot must disengage the autopilot and fly the aircraft manually. Also, as described in section 2.13.3, it is mentioned in the JAL OM that "the autopilot shall not be manually overridden during flight under autopilot control. Also, the autopilot shall not be disconnected while force is being applied to the control column", and further detail explanations were given in "Operation News".

(2) As described in section 2.12.4(1), JAL conducted flight simulator training to allow crews to experience high altitude, high speed flight characteristics, which included manual maneuvering. However, there were no training items by which crews could experience high altitude manual handling characteristics, in particular, the fact that the same control input at high altitude as at low altitude results in a larger pitch change, and to allow them acquire experience in making small, smooth control inputs.

Further, JAL did not conduct training for pilots to get used to the procedure to change to manual control after disengaging the autopilot and learn characteristic of manual control on a condition that a rapid, large wind change during descent at high altitude results in a rapid change in airspeed causing an approach to or excess of Mmo, and further, stick shaker starts to work. It is considered possible that these matters contributed to the pitch changes in the accident.

As described in (1), there may be cases in which pilots are required to assume manual control in highly demanding flight conditions. And such highly demanding flight conditions may cause pilots to use larger control inputs than required.

As described in 2.11.7(3)②b, in numerical simulations, almost no oscillatory pitch motion and no large vertical acceleration occurred when slow control input with appropriate magnitude was applied to reduce the aircraft's pitch angle and the elevators were then fixed. Further, as described in section 2.11.9(2)②b, in flight simulator tests, when the autopilot was disengaged and smooth control column inputs were applied to reduce speed to recover from the approach to Mmo, there was no tendency for pitch change.

However, it is thought that when assuming manual control under highly demanding flight conditions, control inputs such as those described above that do not cause rapid changes in the aircraft's attitude cannot be executed if the pilot only has knowledge, but require the pilot to be trained so that they can be carried out when necessary. Consequently, as described in section 2.11.9, although it is thought that the fidelity of the flight simulator's handling characteristics are not as great at high altitude as they are at low altitude, even if there is some disadvantage in the handling feel, it is important for pilots to train the actions to transition to manual control smoothly after disengaging the autopilot and to learn characteristic of manual control in the cases of approaching Vmo/Mmo, or having already exceeded Vmo/Mmo and also stick shaker beginning to work.

3.10 Use of seatbelt signs and seatbelts

(1) Based on the CVR recording, at around 10:14, when the seatbelt signs were turned off, the CAs made a cabin announcement to keep seatbelts fastened while seated. After that, the captain ordered the seatbelt signs to be turned on during the descent after the pitch changes had occurred.

It is estimated that the seatbelt signs were not on when the accident occurred, because, as described in section 3.4, the flight crew had not anticipated a strong windshear encounter during the descent.

Further, it is estimated that that the seatbelt signs were not turned on when the first large upset occurred because the captain was too busy dealing with the speed increase to switch on the seatbelt signs.

(2) The upset occurred shortly after the aircraft had started to descend, and according to the statements of the CAs and passengers, it is estimated that the seatbelt signs had not been turned on at that time. It is estimated that in the cabin at that time, the CAs had finished the cabin beverage service and were conducting cabin sales, or were tidying up after the cabin service.

According to passengers' statements, all three of the passengers who were seriously injured had been seated but had not fastened their seatbelts. Fifteen out of the 18 passengers who sustained minor injuries had been seated, but nine persons either had not fastened their seatbelts or were unsure of whether or not they had done so. On other words, of the 18 persons who sustained injury while seated, 12 had not fastened their seatbelts and 6 persons had done so.

Given that many of the injured had not fastened their seatbelts, particularly those who were seriously injured, and considering that three out of the six persons who had been injured while their seatbelts were fastened had not fastened them properly, in order to minimize the occurrence of injuries it is necessary that seatbelts are properly fastened in any time while seated.

It is estimated that since the CAs were either carrying out cabin sales or were tidying up after the cabin service, none of the CAs had been seated.

If rapid aircraft motions occur as during the accident, there is a high possibility that passengers walking in the aisles, etc. and CA carrying out their duties may float up and sustain injury. It is considered that installing easily graspable hand grips etc. in the aisle would be effective in preventing injury by keeping bodies from floating up during such upsets.

3.11 Conditions under which injuries were sustained

In the aft cabin, three passengers and a CA were seriously injured in the accident, while 14 passengers and five CAs in the aft cabin, and four passengers and six CAs in the forward cabin sustained minor injuries.

Based on the estimates of the vertical acceleration at the cockpit and aft cabin in Figure 4, it is considered that vertical accelerations were created which were larger in the aft cabin than in the forward cabin as described in section 2.11.8, as a result of which it is estimated that all of the serious injuries and the majority of minor injuries occurred in aft cabin.

None of the seriously injured had fastened their seatbelts. It is estimated that these persons were seriously injured when their heads etc. hit the ceiling or when they hit their backs etc. when falling to the floor. There were also some persons who had sustained only minor injuries when they had floated up while sitting without their seatbelts fastened, but it is possible that they could have been seriously injured by hitting the ceiling or falling to the floor in the same way.

On the other hand, although it is estimated that the majority of the passengers had fastened their seatbelts, it is considered that serious injury can be prevented by reinforcing use of seatbelts while seated even if the seatbelt signs are turned off.

3.12 Rescue Activities

3.12.1 Rescue activities in the cabin

Based on the statements of CAs and passengers, and on the CVR recording, it is estimated that just after the upset occurred the seatbelt signs came on and so the CAs made an announcement for passengers to fasten their seatbelts.

Further, it is estimated that the CAs checked the injury situation of the passengers in the cabin, and the situation was reported to the flight crew through the CP.

It is estimated that the rescue activities in aft cabin was carried out by CAs asking passengers to confirm whether there had been any injuries, and that first aid etc. had been administered using medical kit and doctor's kit and with the assistance of doctors and nurses who were among the passengers. However, in the reports from the CAs to the flight crew regarding the injury situation, initially only three passengers were reported as having sustained heavy injuries, and it is estimated the flight crew requested ambulances from ground staff based on that information. Thereafter, it is estimated that the CAs did not report to the flight crew the passengers who were judged to only have light injuries.

3.12.2 Rescue activities on the ground

JAL's Haneda Airport Office received a request for ambulances from the aircraft at around 11:06, and the office's Passenger Department made a request for ambulances by a 119 emergency call at around 11:16. It is thought that at that time, the Passenger Department communicated that there were three persons injured, that the estimated arrival time of the aircraft was 11:24, that the aircraft was planned to arrive at spot No. 12, and that they would stand by at gate No. 4 in the terminal.

Tokyo Fire Fighting Agency received information that three persons had been injured, and made a dispatch order to the Kamata Fire Fighting Office, the Haneda Branch Office of the Kamata Office, and the Sanya Branch Office of the Ohmori Office for total three ambulances, one from each office, because one ambulance is normally dispatched per injured person.

It is estimated that the ambulance arrived in front of the gate No. 4 at 11:29–34, six minutes after the aircraft had landed.

When just as rescue activities in the cabin were starting at around 11:50, because a total of nine persons were confirmed injured, a further two ambulances were requested; then, at around 12:18 a total of 14 injured was confirmed and a further request for ambulances was made to the headquarters office by radio.

In the accident, it is considered that there were an additional two requests made for ambulances because initially only the number of those seriously injured was reported, but that passengers declared minor injuries after landing.

4. PROBABLE CAUSE

In this accident, while the aircraft was descending, a rapid increase in the aircraft's pitch angle followed by pitch changes occurred which caused passengers and cabin crew to float up and be seriously injured when they hit their heads etc. against the ceiling and when they fell to the floor and hit their backs etc.

Contributing to the occurrence of serious injury when the pitch changes occurred were the facts that the seatbelt signs were not turned on at the time, that some passengers who were seated were not using their seatbelts, and that the cabin attendants had been carrying out their duties.

It is considered that the rapid increase in pitch and the subsequent pitch changes occurred through the following process:

(1) Airspeed (CAS/Mach number) increased rapidly due to encountering a strong windshear, and the autopilot responded to reduce the aircraft's speed.

(2) The aircraft's pitch angle increased rapidly. It is considered possible that the speed brakes were used at that time.

(3) The autopilot was disengaged, and then oscillatory=pitch changes occurred according to the pilot's control column input when manual control was assumed.

Further, it is considered possible that a contributory factor regarding the oscillatory pitch changes was the fact that the pilots had not had sufficient opportunity to experience disconnecting the autopilot and assuming manual control when the Mach number approached Mmo at high altitude, and stick shaker work, or the handling characteristics under those conditions.

5 OPINIONS

5.1 Attention to the possibility of pitch oscillation occurrence

It is estimated that in this accident, the aircraft encountered windshear in flight and over control occurred when a pilot took action to respond to the resulting rapid airspeed change, causing a repeated periodic increase and decrease in the aircraft's pitch angle which resulted in injuries to cabin crew and passengers. Similar accidents involving repeated oscillatory pitch changes (pitch oscillation) as the result of windshear encounter have occurred in Japan in the past.

Even if an aircraft has received type certification after stringent flight testing and has been used for air transportation, the danger of entering pitch oscillation like this is not generally widely known. It is said that cases in which the amplitude of the oscillation was small have often gone unrecognized as occurrence of pitch oscillation. Even if the flight data recorder on which the flight operation processes are recorded is inspected, because the data recording time interval is greater than for recorders used in flight testing, it is often difficult to positively identify the occurrence of pitch oscillation.

As a result of the above, the actual situation of pitch oscillation occurrence in aircraft that have entered operation has not been accurately determined. Since the occurrence of pitch oscillation involves the aircraft's characteristics, and since in addition it is difficult to predict in advance, it is not always certain that it can be reproduced by a simulator. Consequently, when previous cases are examined, even if they are extremely rare, it is considered possible that future accidents or incidents due to the occurrence of the same sort of pitch oscillation may recur.

There is not always an effective means to avoid the occurrence of harmful pitch oscillation. But, it is thought that the possibility of oscillatory pitch motion occurrence may be increased in the case where it is necessary for a pilot to control an aircraft manually without using the autopilot because of rapid changes in wind speed etc., if pilot makes large, rapid control inputs, and it becomes over control opposite to the pilot's intention due to a dynamic response involving the pilot's control inputs and the time lag of the aircraft's response. In particular, because aerodynamic damping of the aircraft's motion is reduced at high flight altitude and low air density, the aircraft's response to control inputs tends to be sensitive, and consequently it is considered that there is a still greater possibility that pitch oscillation may occur. If pitch oscillation should occur, the pilot should momentarily cease making control inputs or should reduce them to reduce the connection between his response and that of the aircraft; that is, it is thought that removing the pilot from the closed-loop interaction between the pilot and aircraft is effective in stopping pitch oscillation. To reduce the occurrence of accidents involving pitch oscillation, it is important that aircraft operators carrying out air transportation educate pilots to always be aware of the possibility of occurrence of pitch oscillation occasioned by transitory oscillation of the aircraft due to windshear etc., and that such recognition should be continually refreshed.

6 MATTERS FOR REFERENCE

The following measures were implemented by Japan Airlines after the accident.

(1) On January 9, 2003, Operation Information No. 400-177 was issued, and "On stick shaker activation at high altitude" was disseminated throughout the company.
(See Appendix 5)

(2) On November 10, 2003, Operation Information No. 400-184 was issued, and "Response to Overspeed (Vmo/Mmo)" was disseminated throughout the company.
(See Appendix 6)

(3) On November 10, 2003, "Start of training on response to overspeed" was issued, and from November 15, 2003, training to allow crews to experience a simulated overspeed due to a rapid wind change and the responses was added to the Advanced Training for all aircraft types operated by the company.

FIGURE, PHOTOGRAPH AND APPENDIX LIST

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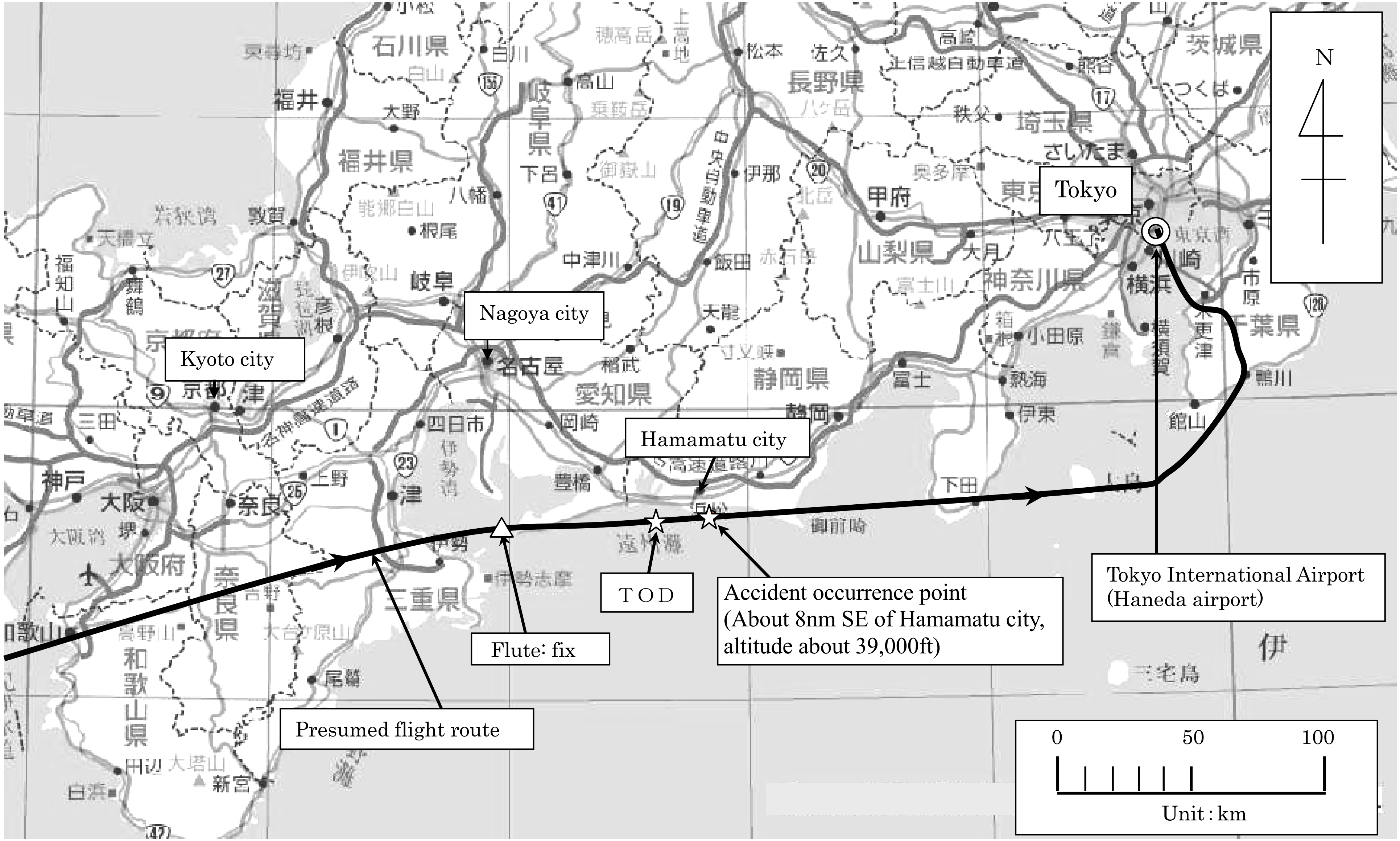
Figure 1 Presumed flight route



株式会社アルプス社　プロアトラス２００２　東海編を使用。

Figure 2　Three angle view of Boeing 747-400D

Unit：m

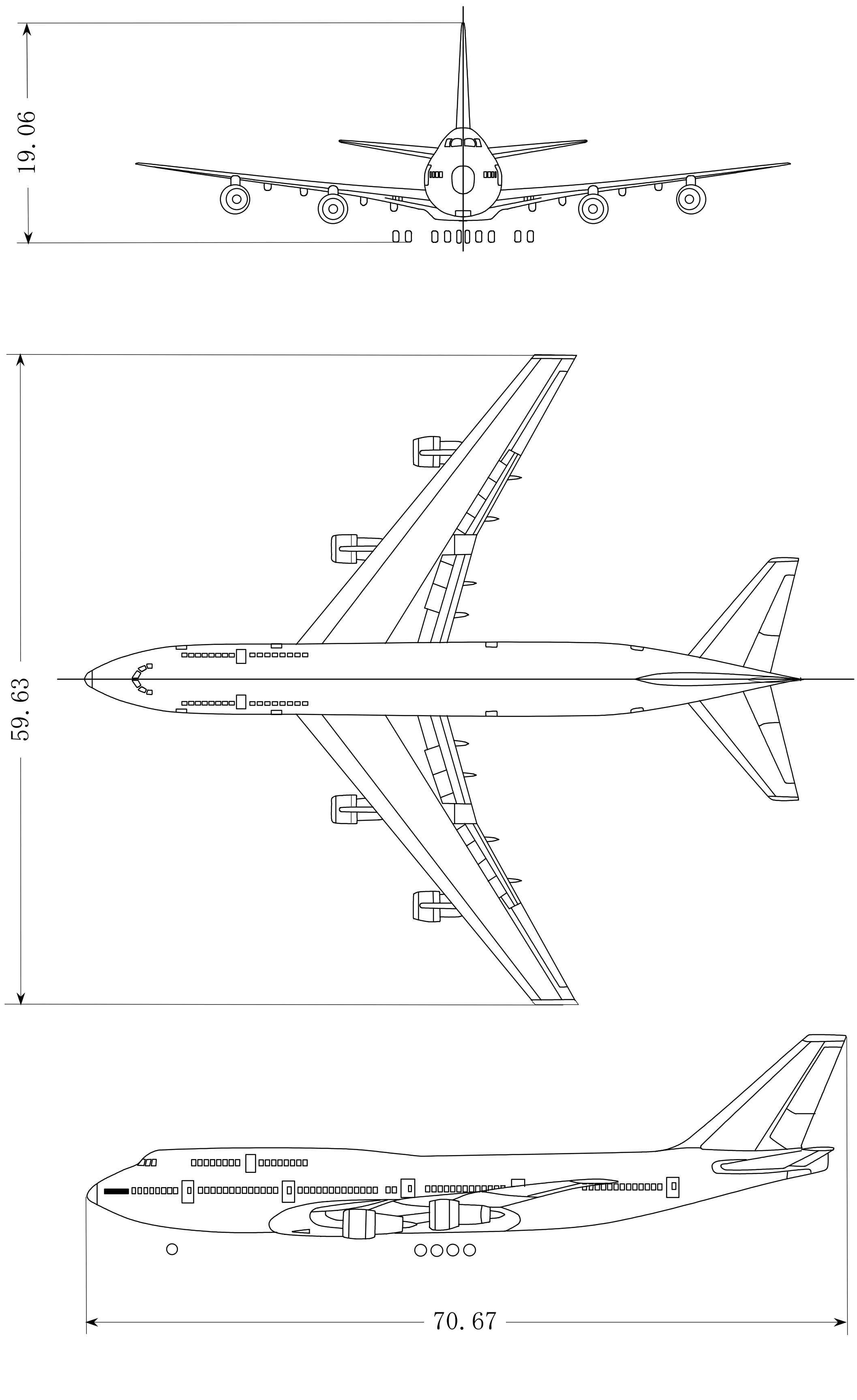


Figure3-1　DFDR data-1

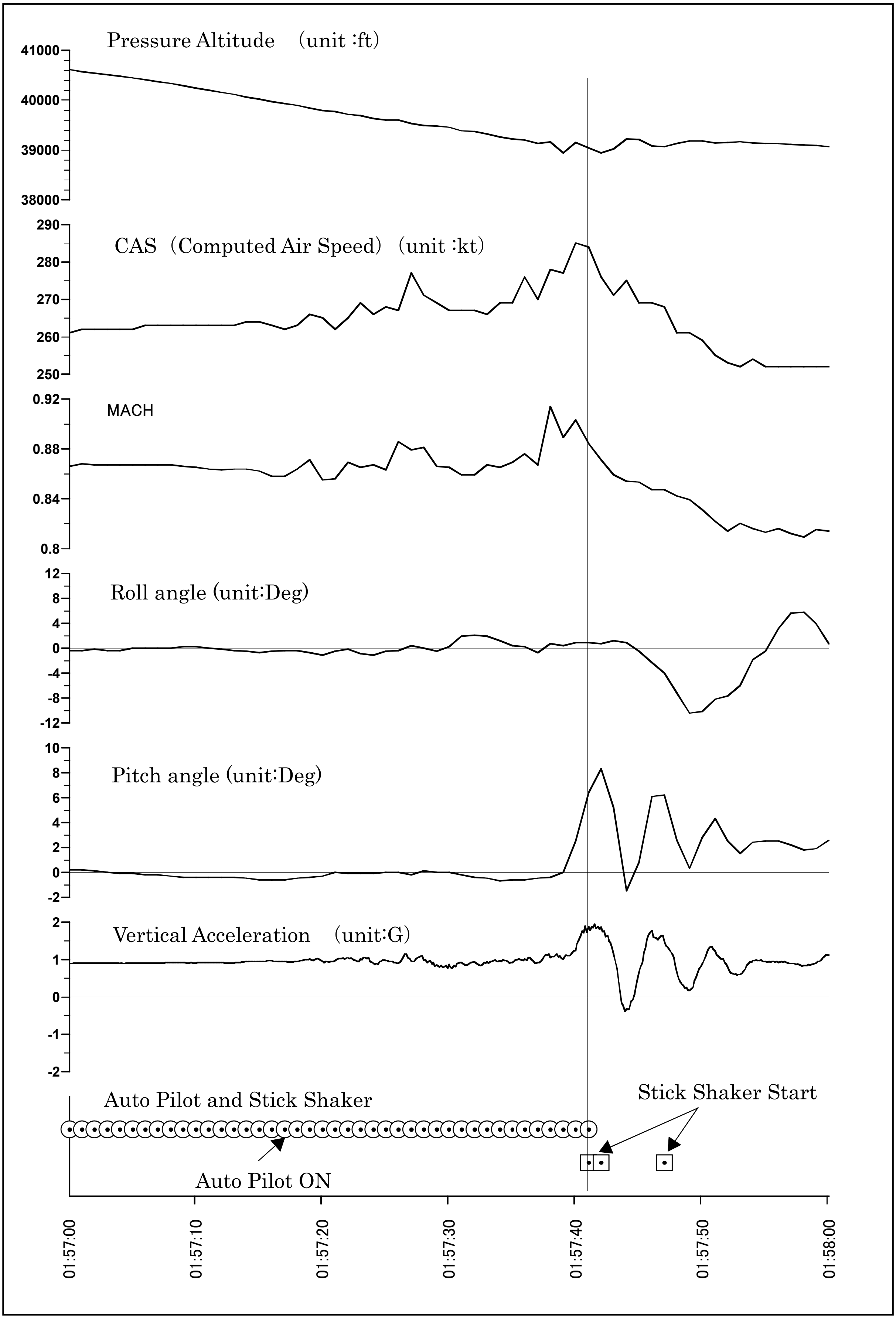


Figure3-2 DFDR data and ACMS data-2

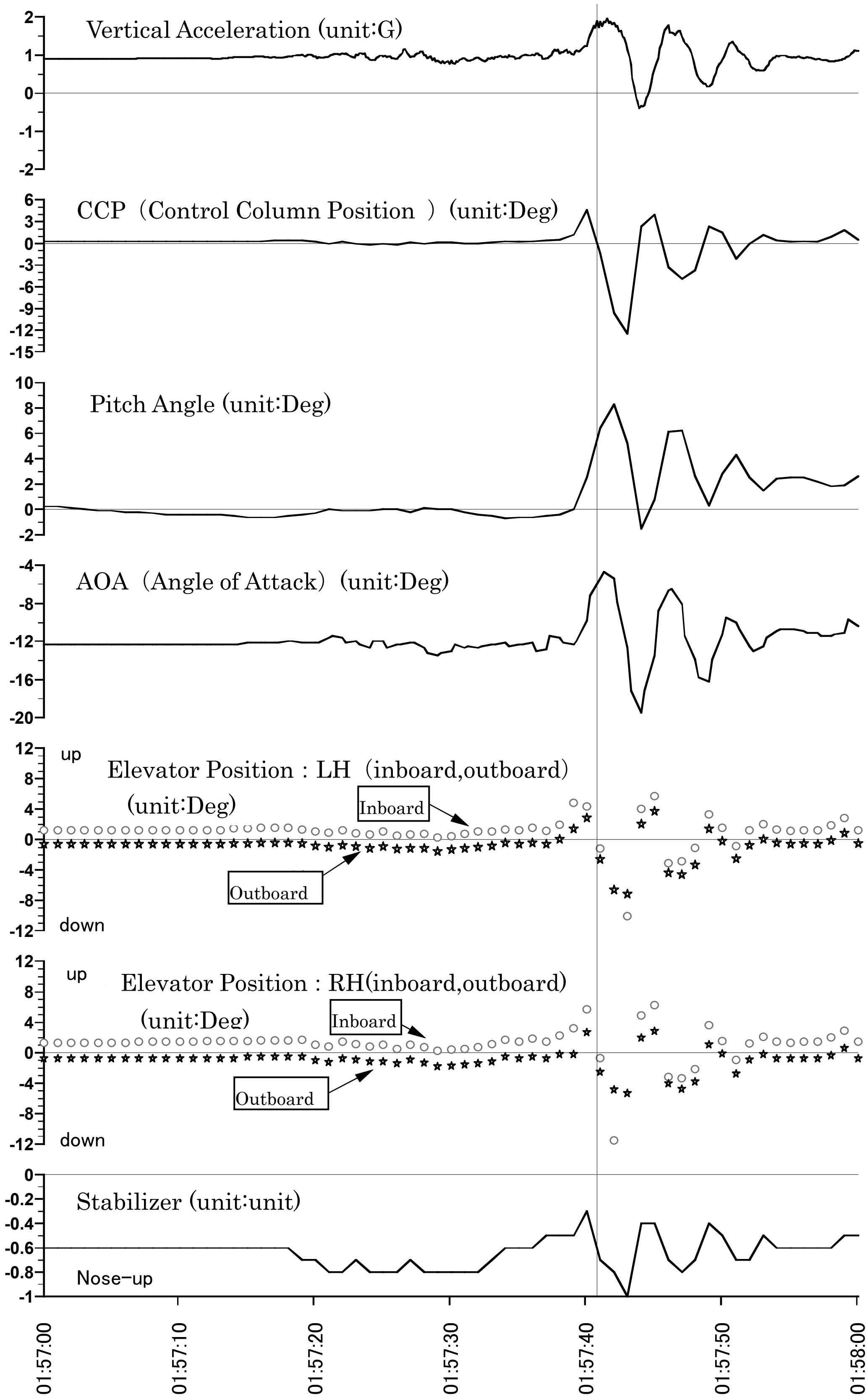


Figure3-3　DFDR data-3

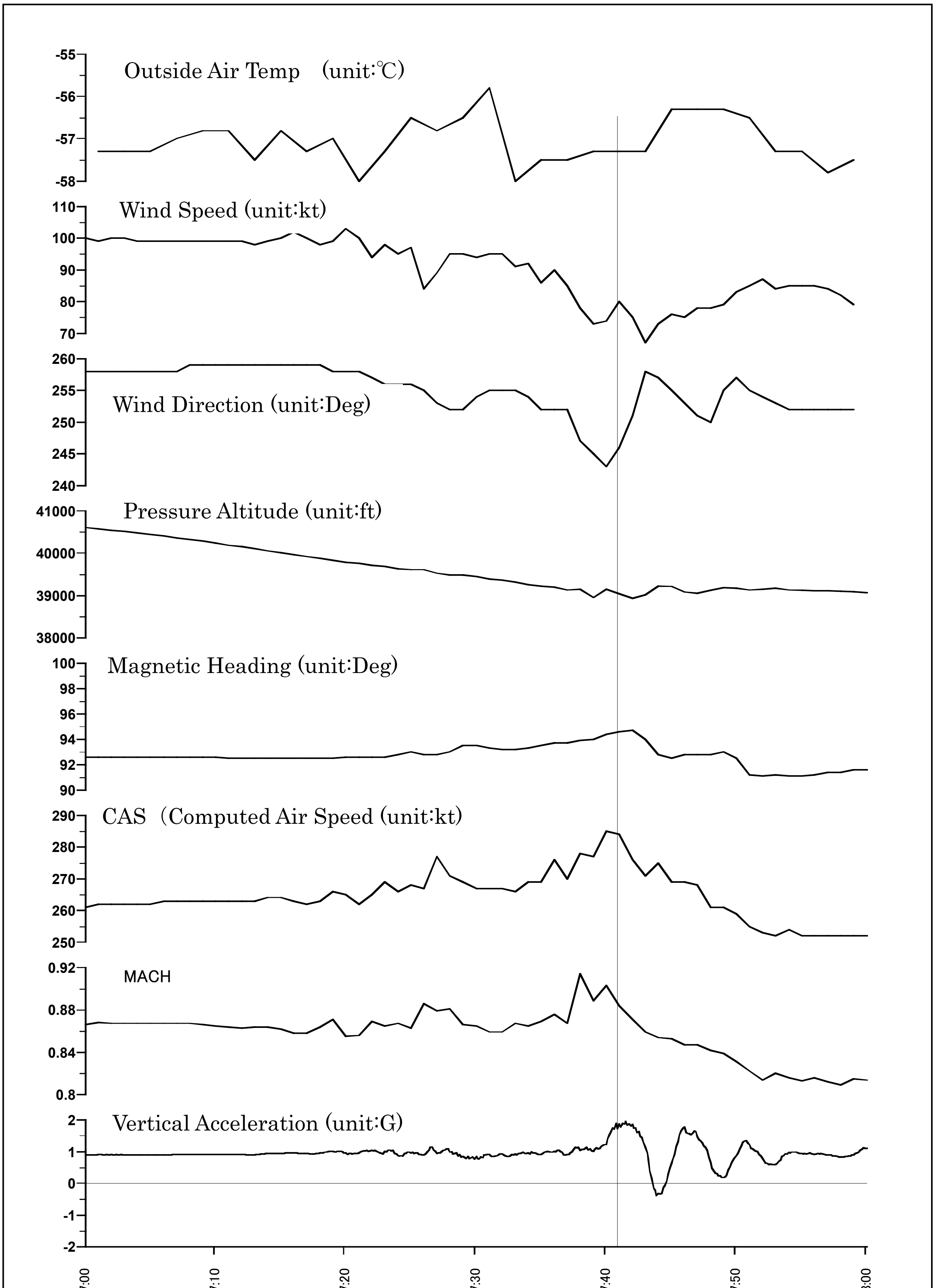


Figure3-4 DFDR data-4

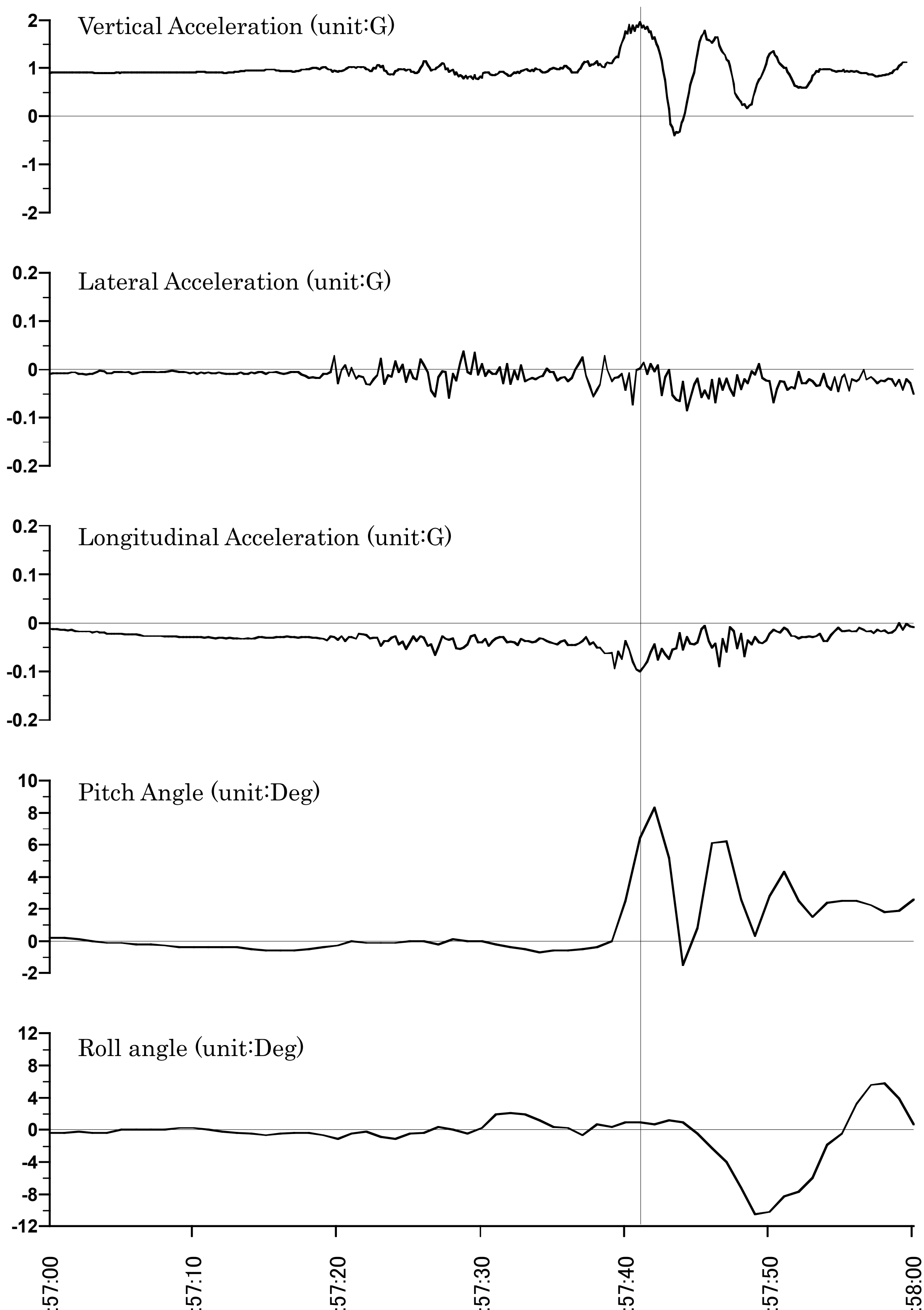
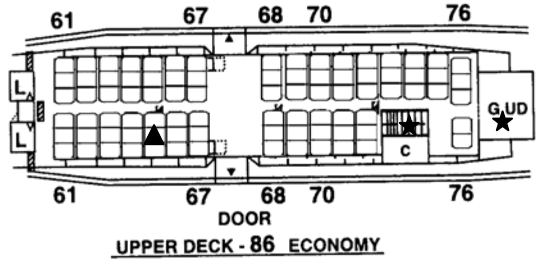


Figure 4　Injuries Layout



●	Serious（Passenger:3、Not fastening seatbelt）
⬣	Serious（CA:1）
▲	Slight（Passenger:6, Not fastening seatbelt）
△	Slight（Passenger:3, Not seated）
▼	Slight（Passenger:9,Not fastening seatbelt;7、obscure;2）
★	Slight（CA:11）

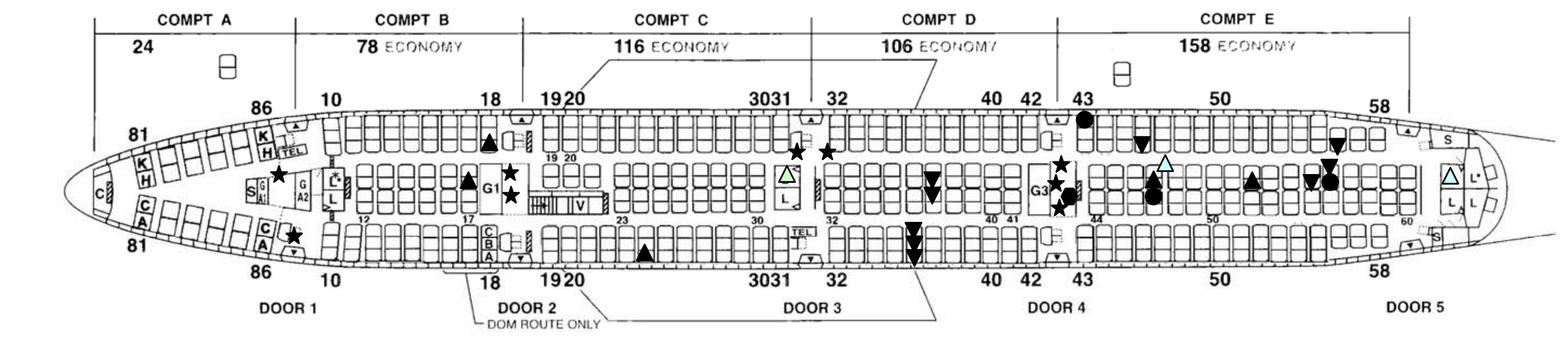


Figure 5 Major damage of cabin

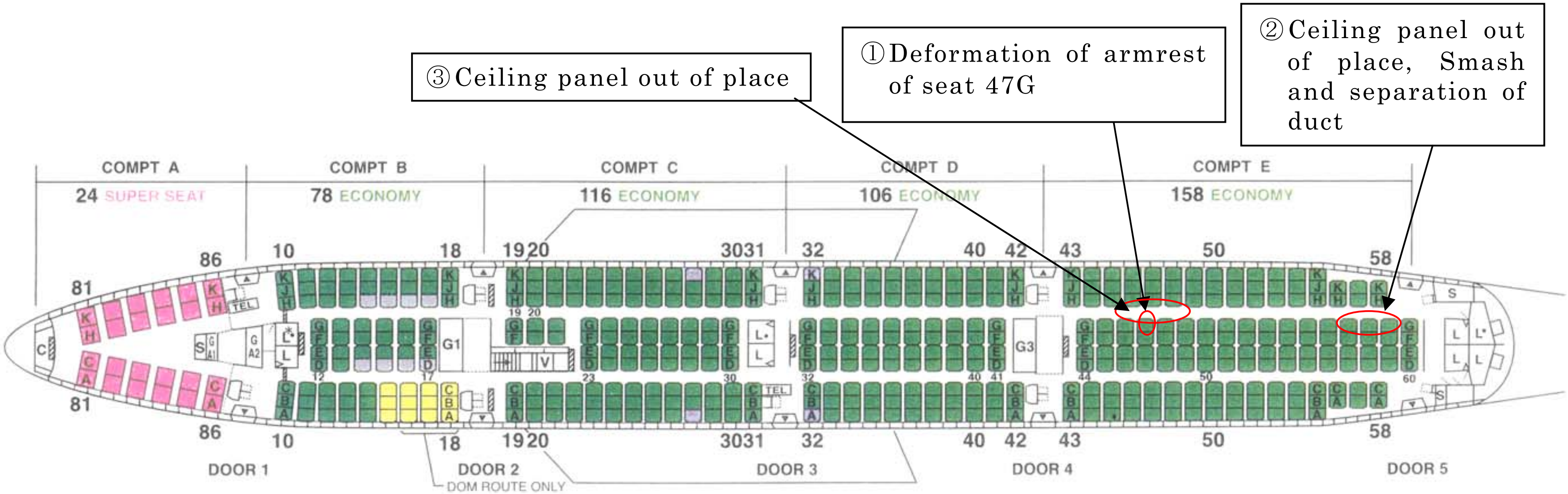


Figure 6-1　Asian Surface Analysis Chart（0900JST, 21 Oct. 2002）

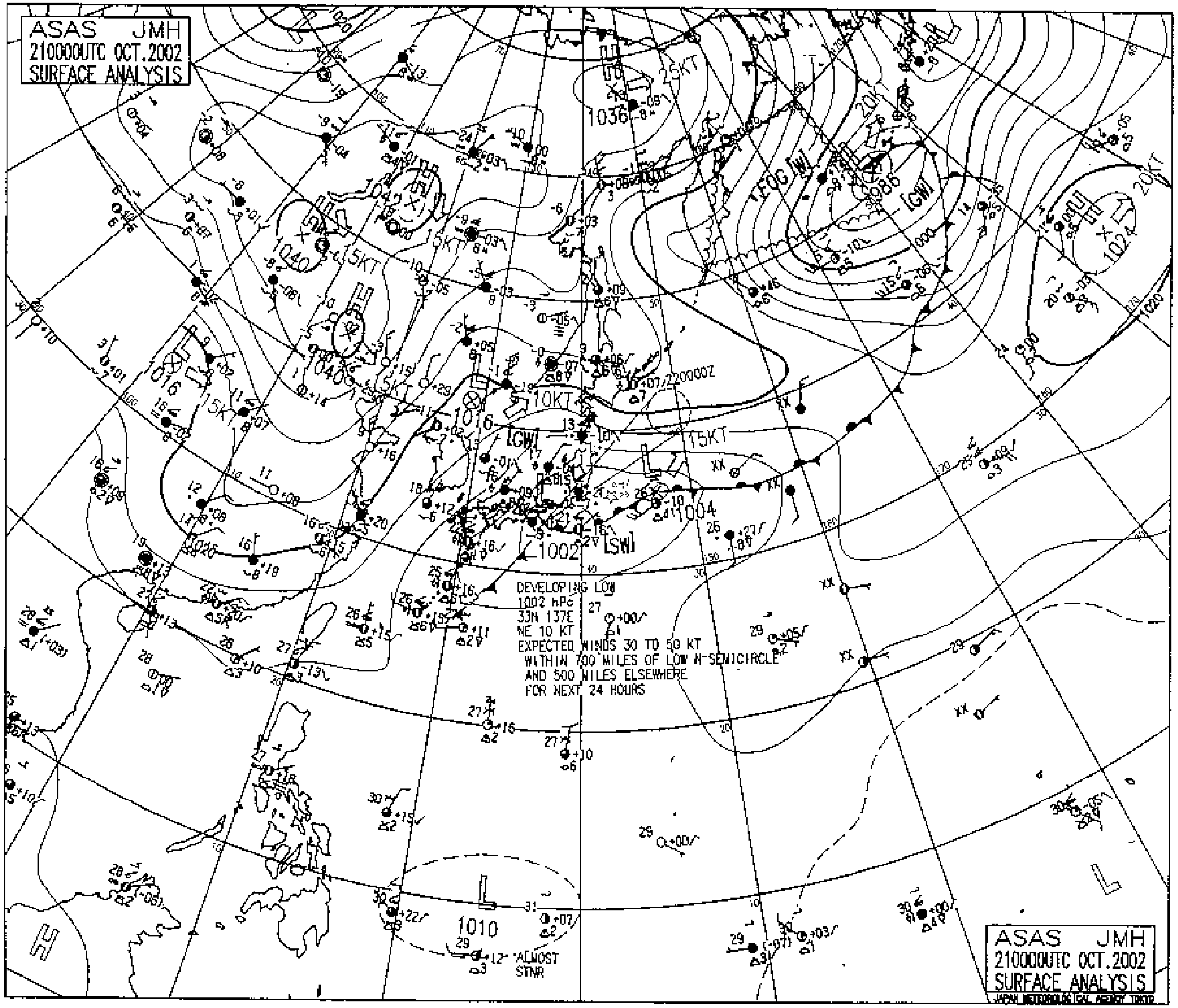


Figure 6-2　Asian Surface Analysis Chart（1500JST, 21 Oct. 2002）

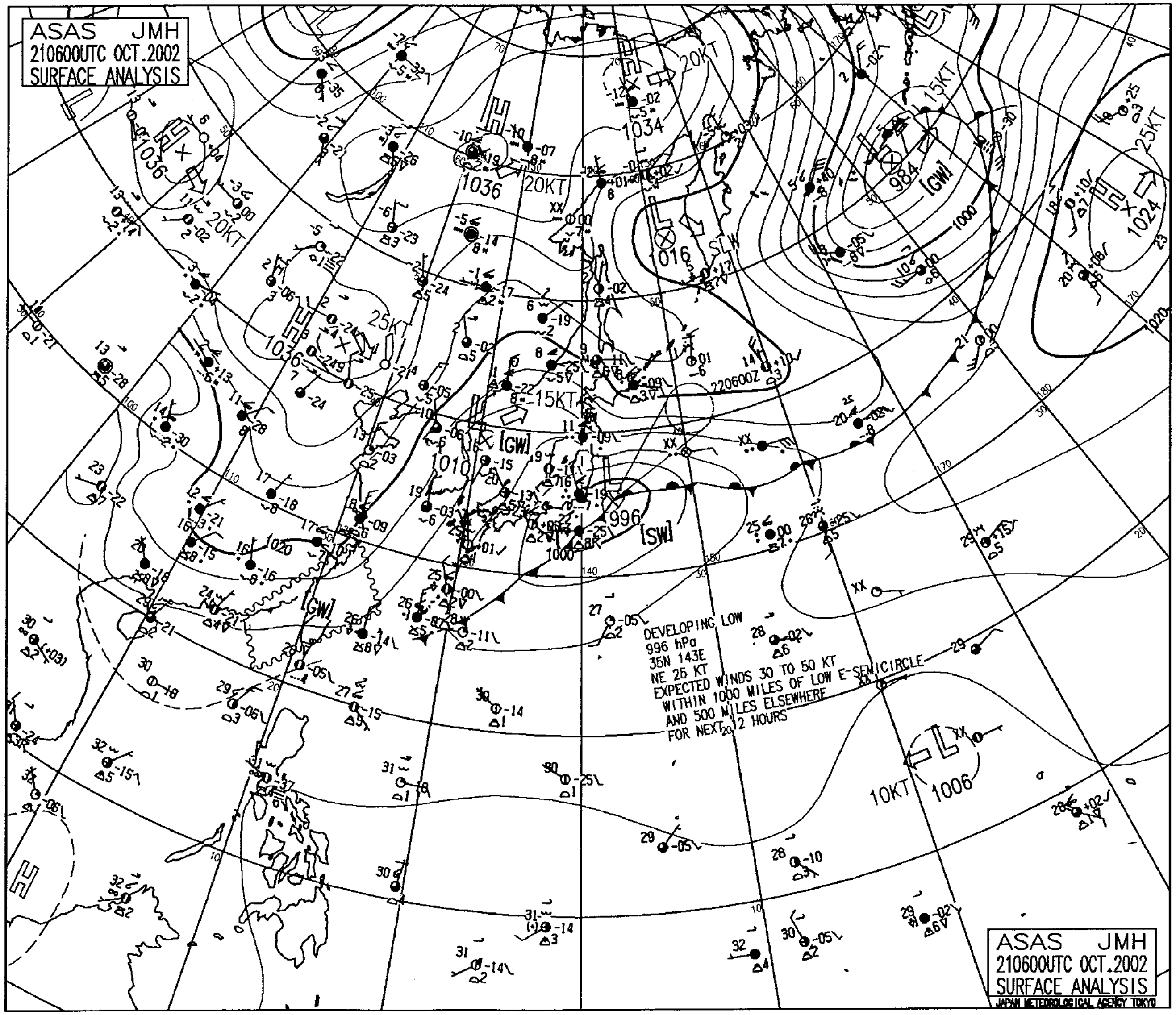


Figure 7　Cloud picture by weather satellite
(Water vapor picture: 1100JST, 21 Oct. 2002)

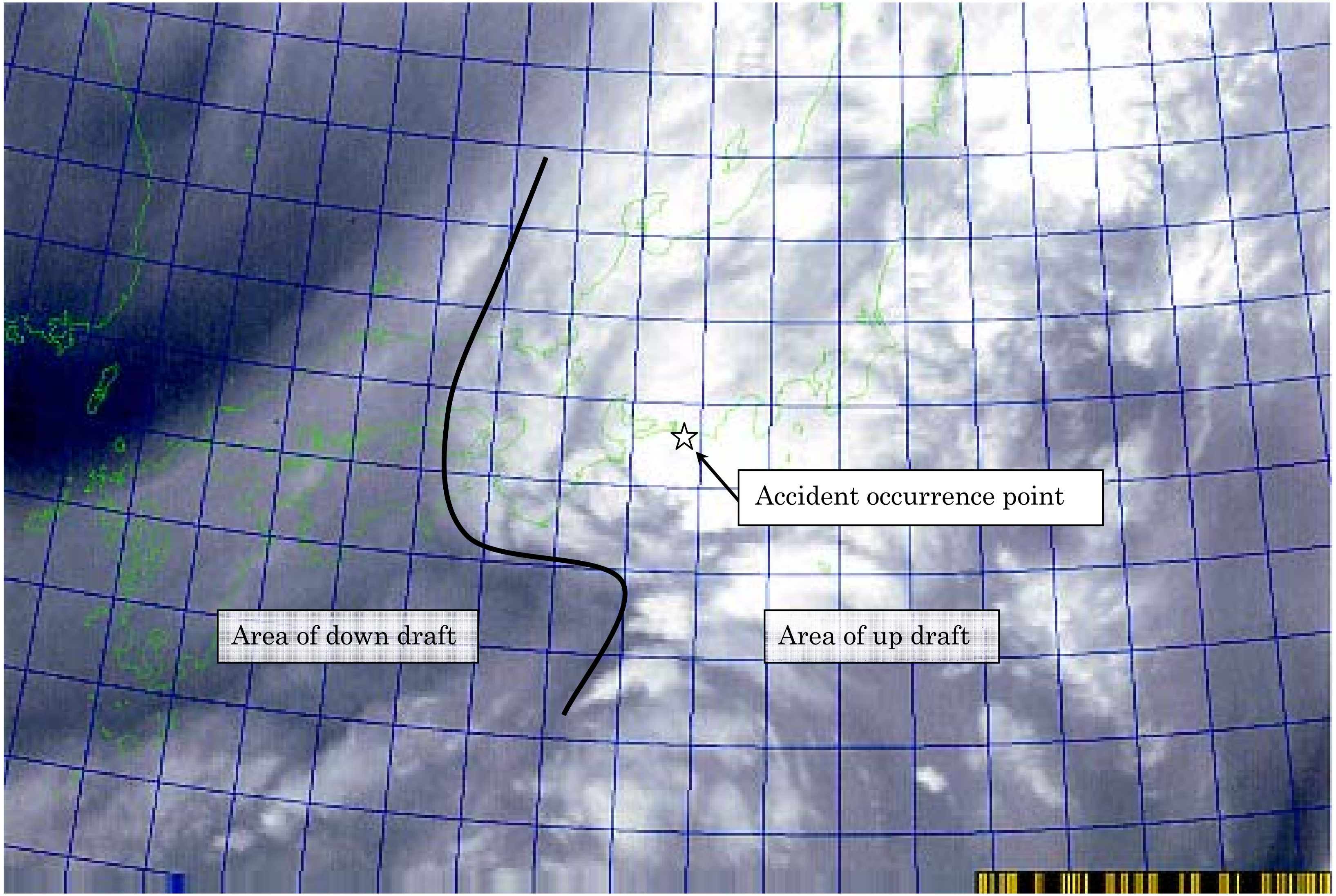


Figure 8　Cloud Information Chart(0900JST, 21 Oct. 2002)

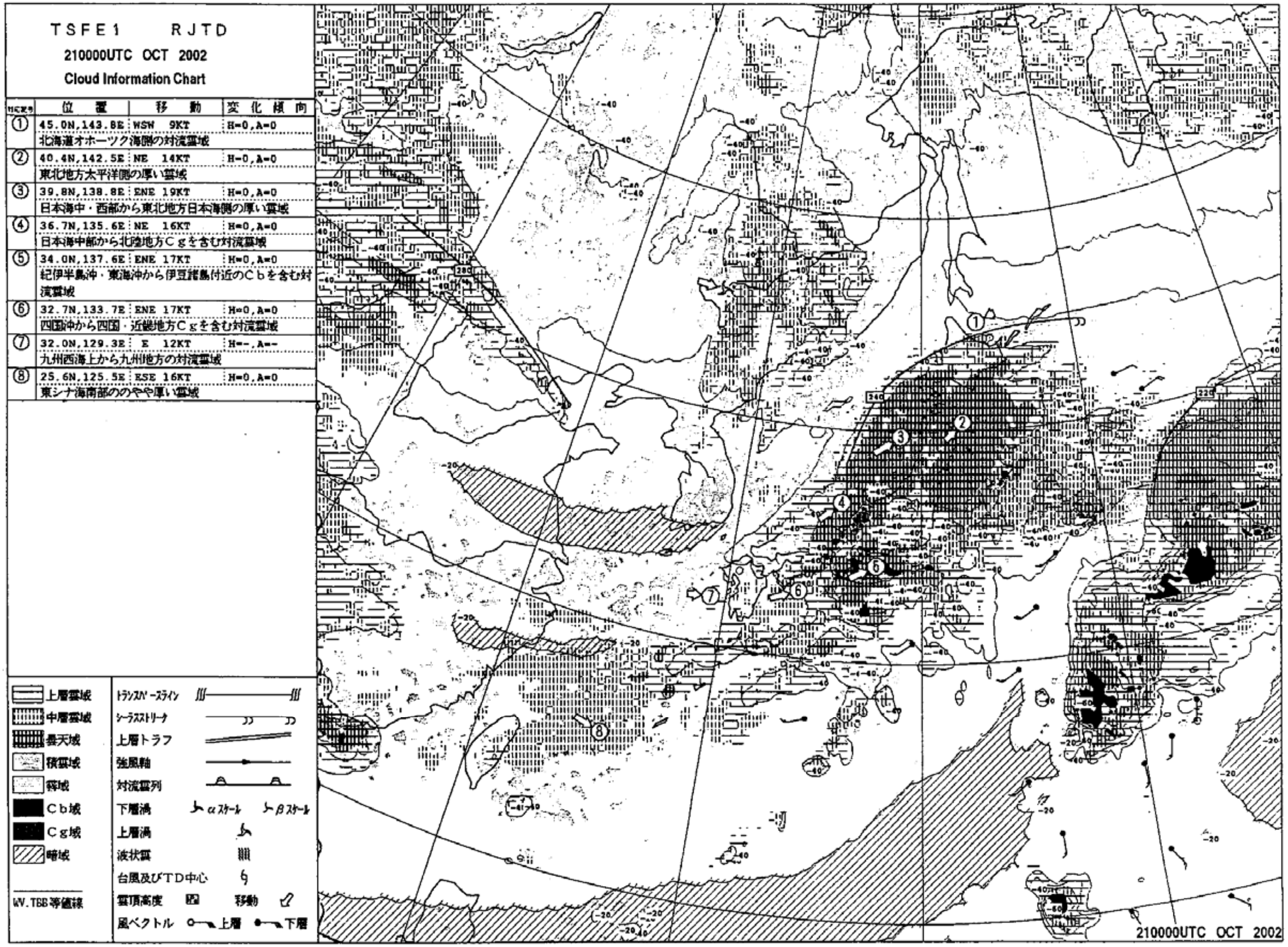
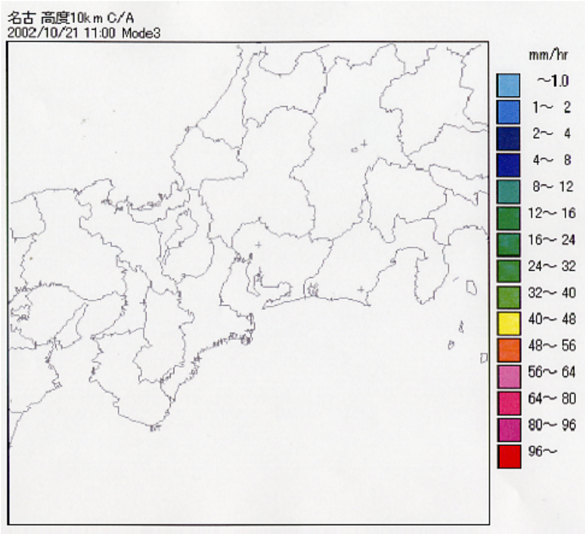
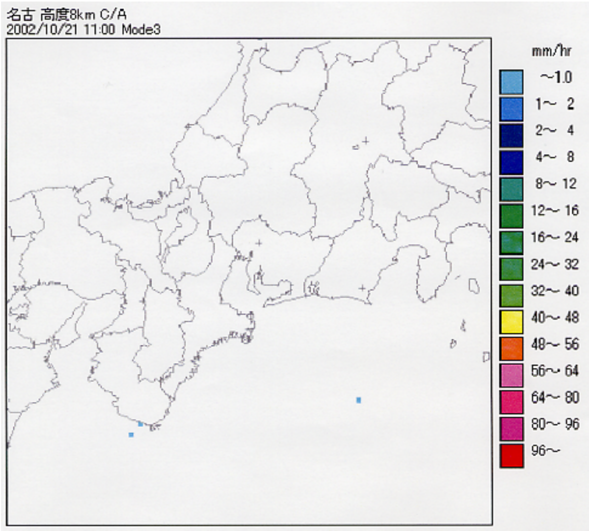


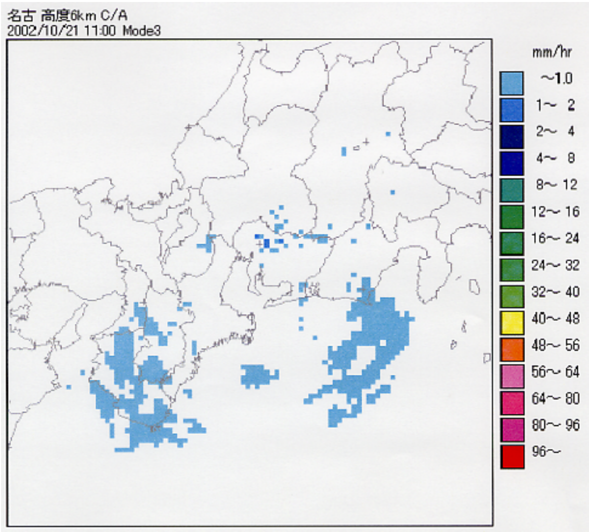
Figure 9　Nagoya RADAR CAPPI Chart
(1100JST, 21 Oct. 2002, Altitude 10km, 8km, 6km)



Altitude : 10km



Altitude :8km



Altitude :6km

Figure 10　Asian 200hPa Chart

(2100JST, 20 Oct., 0900JST and 2100JST, 21 Oct. 2002)

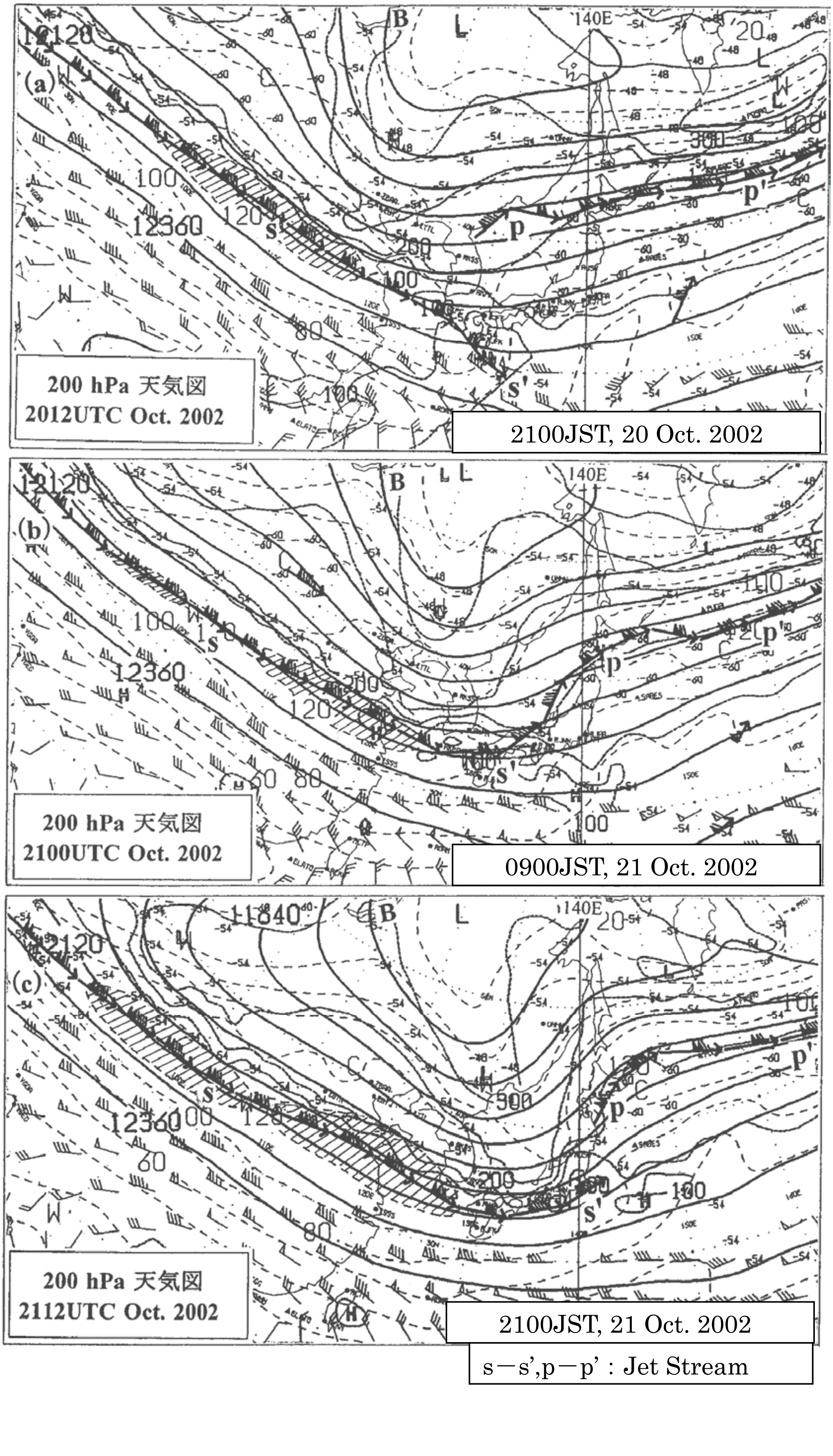
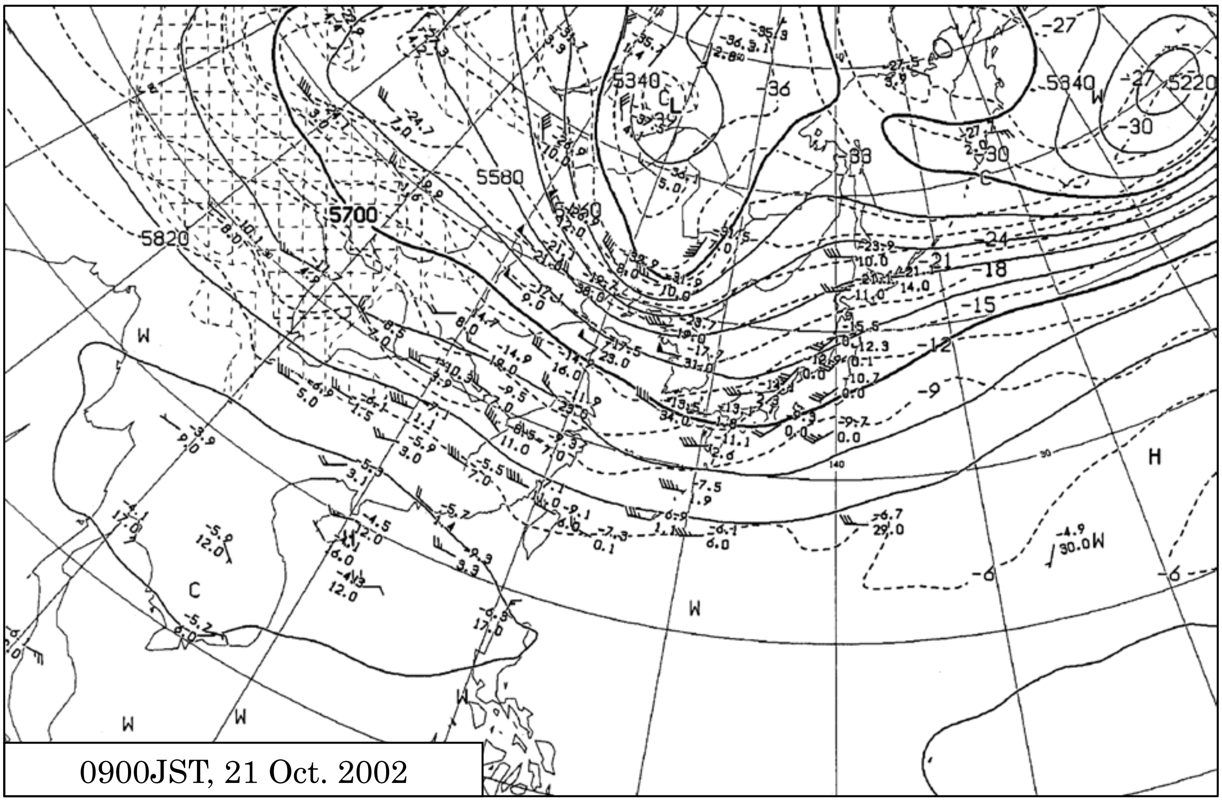
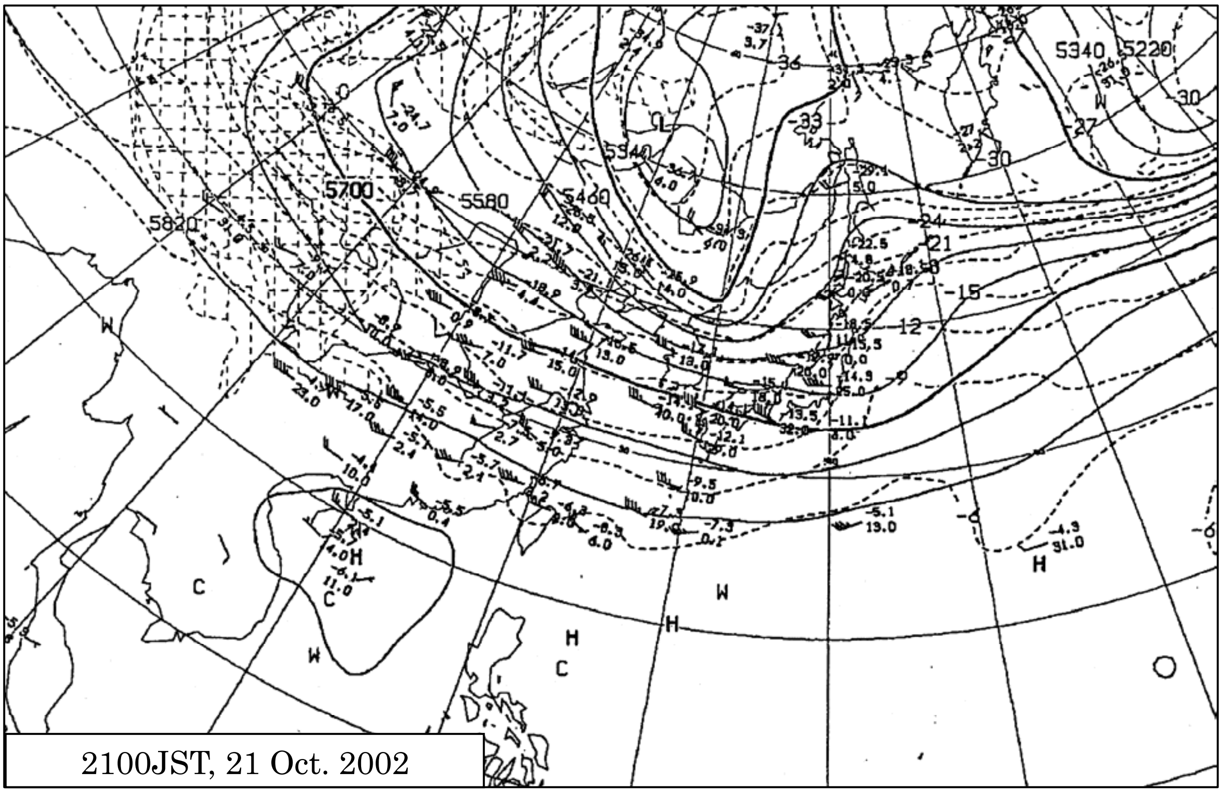


Figure 11　Asian 500hPa Chart

(0900JST and 2100JST, 21 Oct. 2002)

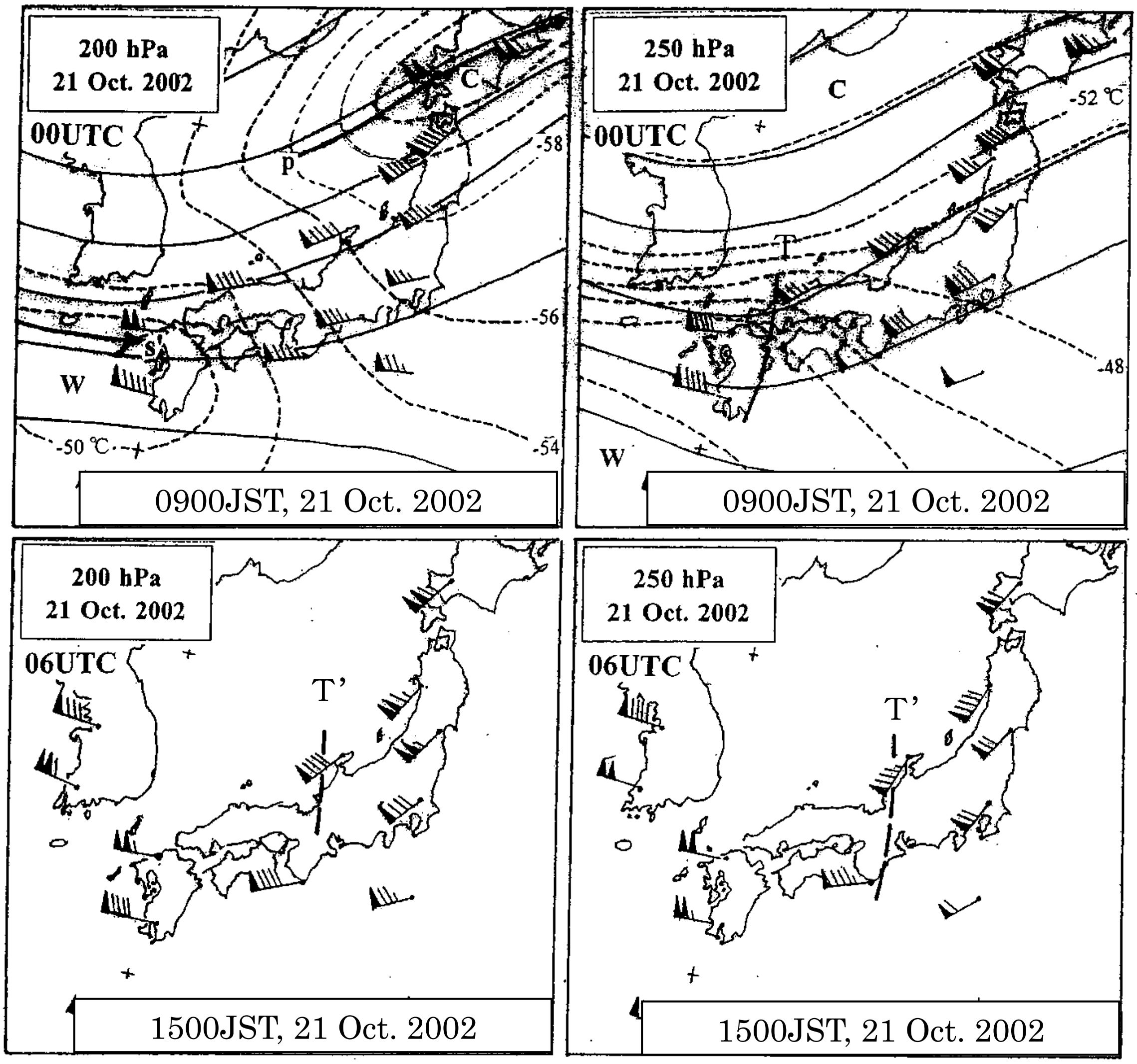


0900JST, 21 Oct. 2002



2100JST, 21 Oct. 2002

Figure 12　200hPa and 250hPa Chart
(0900JST and 1500JST, 21 Oct. 2002)



s'	: Jet Stream (East edge)
p	: Jet Stream (West edge)
T,T'	: Trough（Trough of low pressure）

Figure 13　Area Meteorological Advisory Chart(0000～0900JST, 21 Oct. 2002)

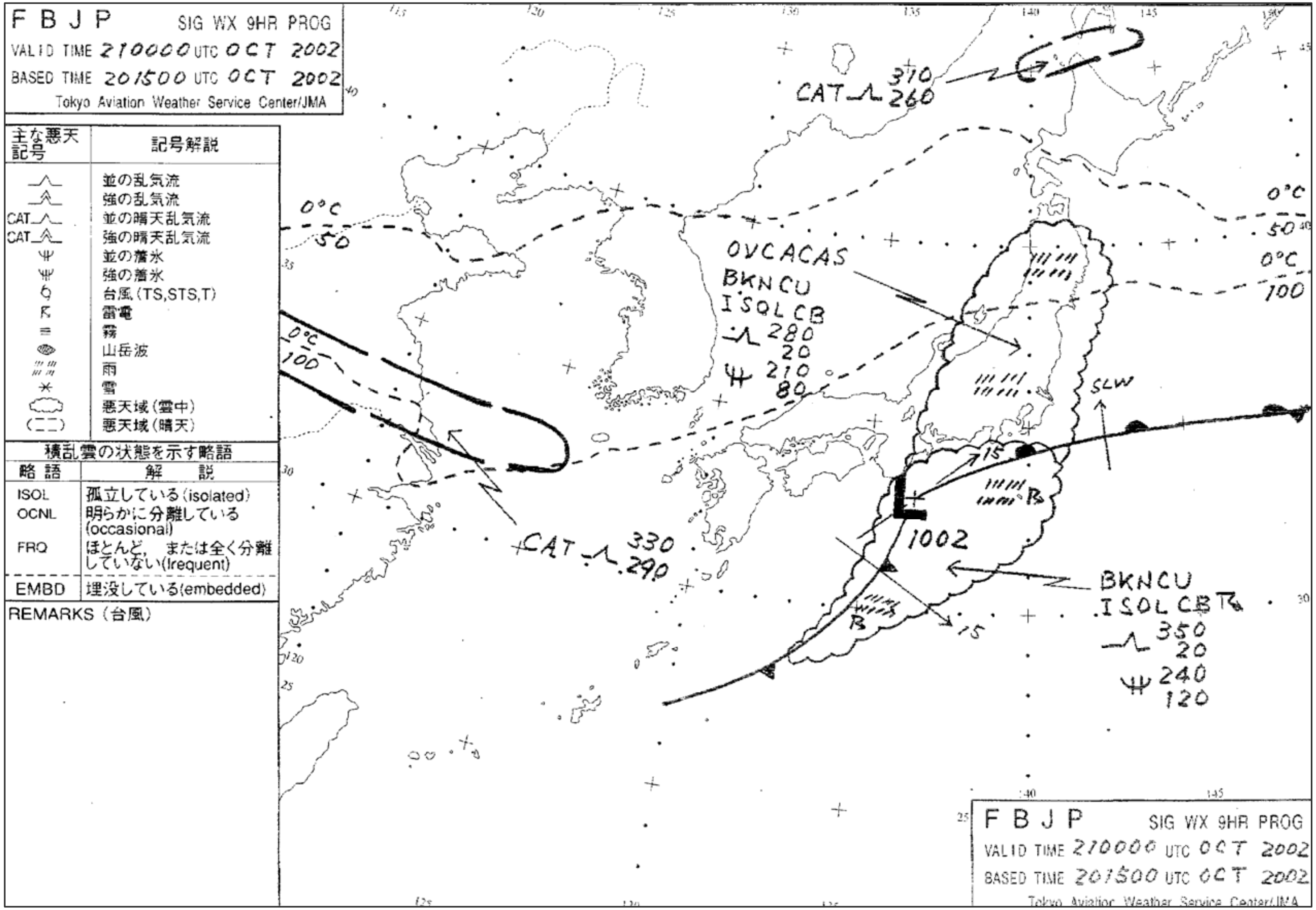
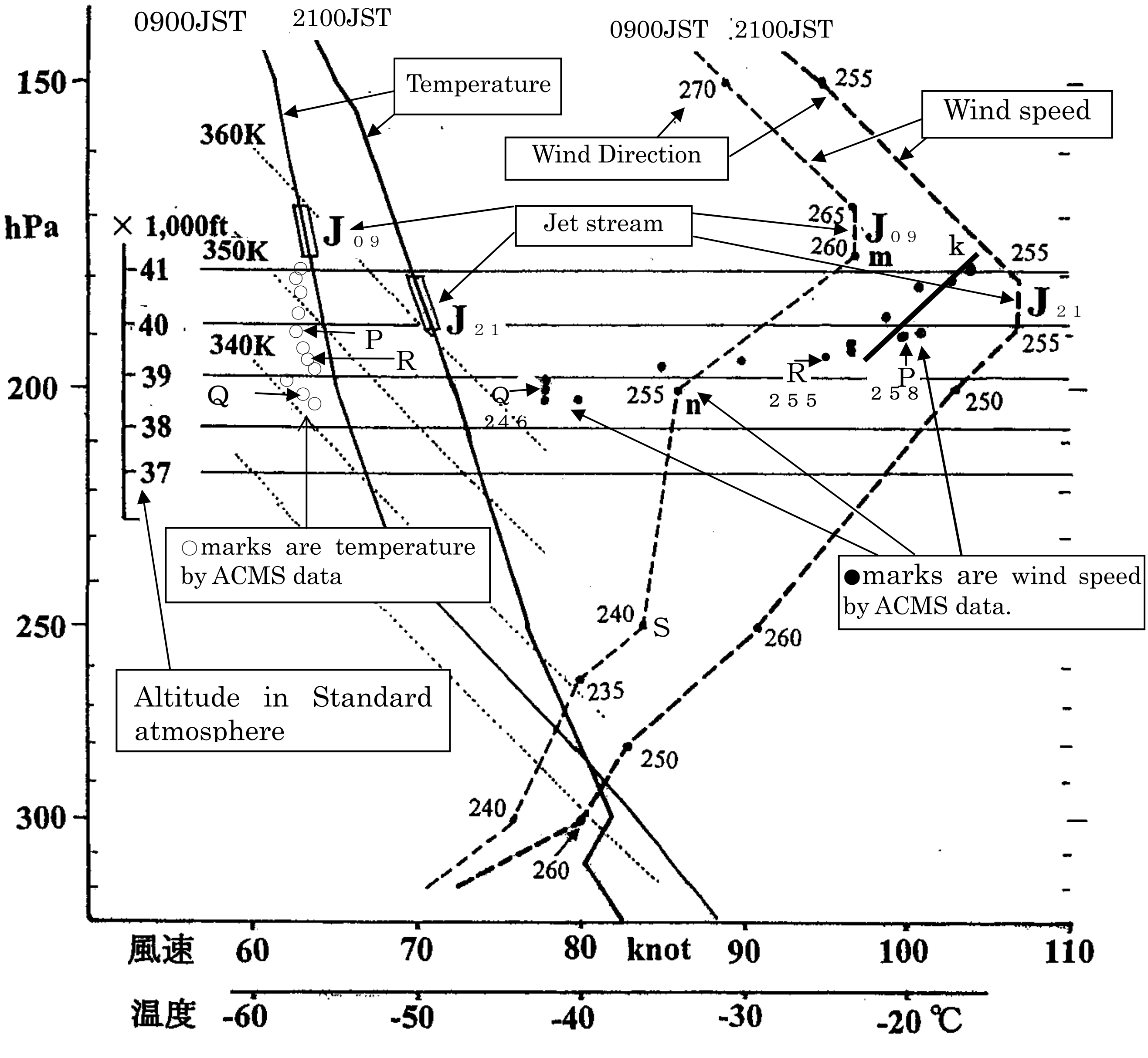


Figure 14　Temperature and Wind speed distribution over Hamamatu (0900 and 2100JST, 21 Oct. 2002)



(Note)　Character "J" in the chart indicates Jet stream, and it shows Temperature and Wind speed at the altitude around the time of accident.

Numerals around wind graph indicate wind direction.

Photograph 1　Damaged Seat

Photograph 2　Ceiling Panel out of place

Photograph 3　Smash and Separation of Duct

APPENDIX 1　Cockpit Voice Recorder Transcript

??? : indicates unintelligible word.　　　・・・: indicates pause.

Time (JST)	Source	Content
Approx.10:14	CA	Ladies and gentlemen, the seatbelt signs have now been turned off, but we may encounter turbulence in flight. Please fasten your seatbelt whenever you are seated for your own safety.
1055:04	F/O	Contact and request lower, please.
1055:08	Captain	"Tokyo Control Japan air 356, request descend"
1055:12	Tokyo CTL	"Japan air 356 roger, descend and maintain Flight level 160, cross SPENS at Flight Level 160"
1055:18	Captain	"Descend cross SPENS at Flight Level 160, Japan air 356"
1055:25	F/O	Right, we'll start to descend from Top of Descent.
1057:10	Captain	"Tokyo Control, Japan air 356 leaving 410 for 160"
1057:28	Captain	Speed, Speed.
1057:33	Captain	Make an intervention, and bring it back more・・・・・
1057:41		Sound of stick shaker. (3 seconds)
1057:43	Captain, F/O	"I have control" "You have control"
1057:45		Small metallic sound of "Click"
1057:47	Captain	Belt on
		Sound of stick shaker. (2 seconds)
1057:50	Captain	Ignition on
1058:03	CA (PA)	Ladies and gentlemen, please fasten your seatbelts tightly.
105838	Captain (PA)	Ladies and gentlemen, from the cockpit. We are now flying in bad turbulence air due to wind changes. Please return directly to your seats, cabin attendants also. It should get a lot better soon, but please return to your seat and fasten your seatbelt surely.
1059:02	Captain	[In English] Ladies and gentlemen, ???? from the cockpit. Please, return to your seat immediately and fasten seatbelt. We had ???? flight condition due to wind change.

1059:33	Captain	Yes, this is the captain.
1059:34	CA	This is R-4. We had a passenger fall during the turbulence just now, may I go to their seat for a moment?
1059:44	Captain	Please do so. If an ambulance is needed, please tell me.
1100:52	Captain	I'll continue flying her for a while.
1101:19	Captain	Yes, this is the captain.
1101:21	CA	The cabin situation, I've only heard the condition, but a ceiling panel had fallen down and a passenger is bleeding. How long until the seatbelt signs go off?
1101:44	Captain	Errm, I'll keep the seatbelt signs on for about another 10 minutes.
1101:48	CA	I'm worried about the injured passenger, but is it better to remain seated?
1101:52	Captain	Just take care of the injured passenger, please. Please be seated for the other passengers. And, are the carts all right?
1102:00	CA	Errm, the carts are all right, but the juices and so on, the juices and pots in the galley are scattered.
1102:07	Captain	So it'll be all right for another 10 minutes?
1102:09	CA	Should be all right.
1103:26	CA	May I have your attention please. We are now passing through bad turbulence. It is expected that we will continue through the bad turbulence for a further 10 minutes, so please refrain from using the rest rooms while the seatbelt signs are on.
1103:39	Captain	What was the altitude when we were shaking?
	F/O	From 39 to 38
1103:53	Captain	Wind, did you see it?
	F/O	Sorry, I didn't.
	Captain	You don't know?
1103:59	Captain	What was the wind at 39? Eh, it's not recorded. Aah, all right. About 90kt, it was about that.
1104:19	Captain	Er, right, contact company, "I have ATC", and tell them our situation. Passing FLUTE, commenced descent, TB4 at about 39,000, we have injured passengers and

		are taking care of them. We don't have any other information at the moment, so we'll contact you when we know more and whether ambulances are necessary.
1104:27	F/O	Understood. "You have ATC."
	Captain	"I have ATC."
1104:54	Captain	Listen to the ATC with me, all right.
1104:59	F/O (company)	Japan air Tokyo, Japan air 356, we passed FLUTE and while descending just before Yaizu we encountered TB4 turbulence around just on top from 39,000 to 38,000. We have injured passengers, but we don't know their condition yet. If it's necessary to arrange for ambulances, I'll contact you later again.
1105:27	Company	Japan air 356, roger. I'm waiting the report of the injured passengers.
1105:34	F/O	Understood.
1107:35	CA	Regarding the condition of the injured passenger, the passenger hit his head on the ceiling, and it seems the ceiling fell down. The passenger is conscious but bleeding slightly and is unable to move but the surrounding passengers have removed his trouser belt and holding him so as not to move. Another passenger has broken their collarbone, but I don't know anything more except that he's conscious. Also, a cabin attendant has been injured. She has a cut of about 3cm above her eye.
1108:16	Captain	Can she continue her duties? Is an ambulance needed?
1108:55	CA	I'll go and see her condition. I think you'll need to call for an ambulance.
1109:00	Captain	I'll tell the current situation to the company, and request to call ambulance. Nobody's unconscious but I'll have them call for ambulances.
1113:18	CA	Regarding the injured condition, we have one passenger laid down and unable to move, and other two with dislocated shoulders. Please arrange for ambulances. Also, the cabin attendant can't continue her duties.

Following the above are recordings of conversations with CAs related to the condition of the injured, radio communications with the company, radio communications with ATC etc.

The following are omitted.

APPENDIX 2 Wind estimated from ACMS Data

1 Method of estimating wind

The wind vector was computed from the difference between the ground speed vector and airspeed vector. The following data and assumptions were used in computing ground speed and airspeed vectors.

(1) ACMS data used

- Aircraft attitude (Pitch, Roll, and Yaw)
- Absolute values of Airspeed, Track angle, and Rate of Climb and Descent
- Absolute values of Airspeed (CAS), SAT, Pressure Altitude, Angle of Attack, and Vertical Acceleration

(2) Assumptions

- There is no delay in the data.
- The sideslip angle is zero. (since the lateral acceleration, which is almost proportional to the sideslip angle, was small)

Further, the aircraft's attitude angles, which are necessary to correct for the sensor position, were obtained using numerical differentiation of values by spline interpolation of the attitude angle without using data with low recording rates. The angle of attack was corrected using a method described in the simulator mathematical model.

2 Estimated Results

The estimated results are as shown in the chart.

The values of wind direction, wind speed and TAS in the horizontal plane are shown along with the ACMS data.

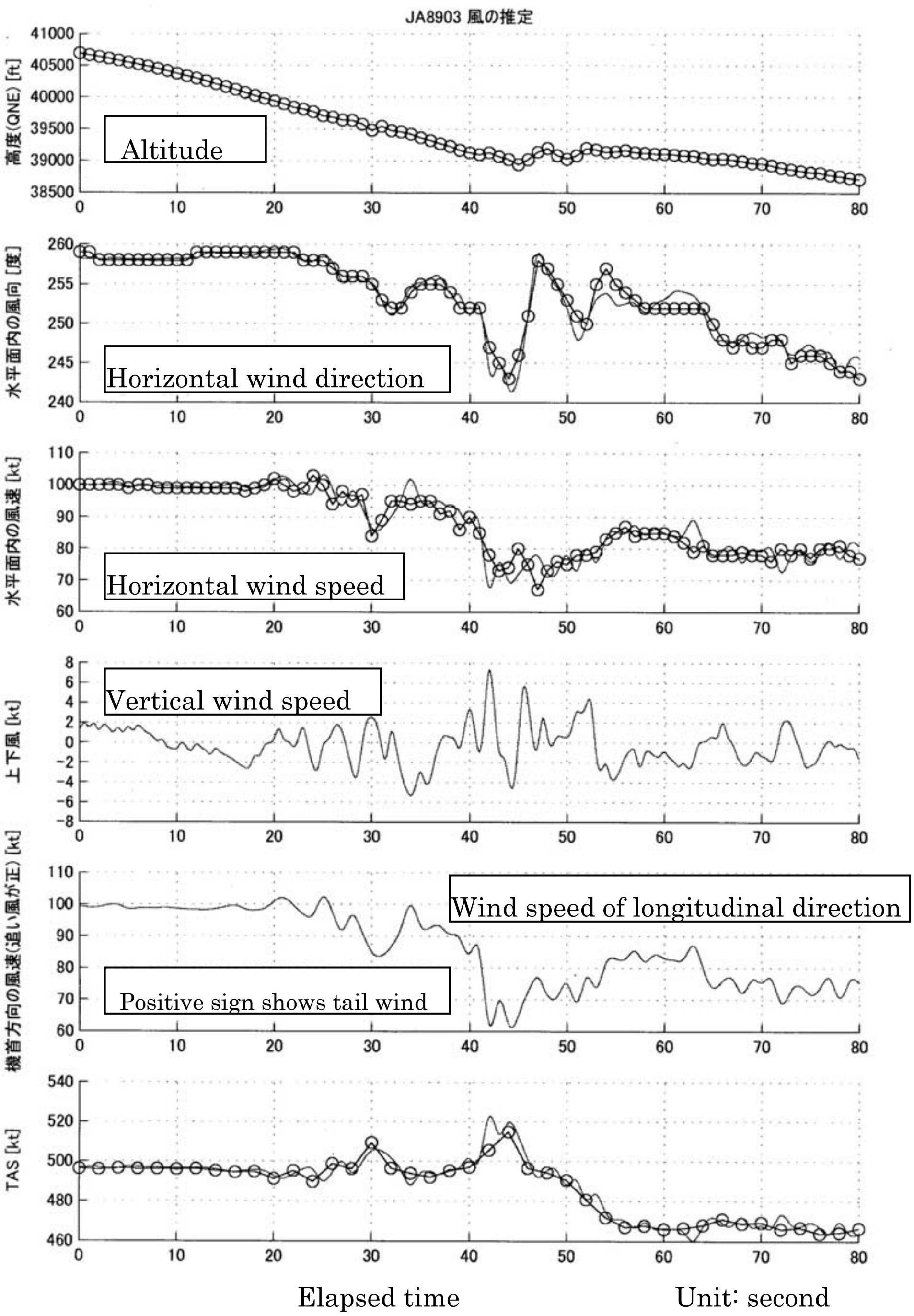
The estimated values are almost coincident with the ACMS data, and show the tail wind component reducing by around 30kt during the approximately 5 seconds before the accident occurred. This is thought to have caused the airspeed to increase rapidly by more than 20kt. Meanwhile, the vertical wind remained steady within $\pm$8kt during the time of the accident. This vertical wind change corresponds to a change of around $\pm 1°$ in angle of attack, and it is difficult to think to this would have significantly affected the aircraft's motion. Although it is possible that the actual peak angle of attack values were greater than the estimated values because of the low recording rate of the angle of attack data essential for the estimation of the vertical wind (1Hz) and since there are problems with the dynamic characteristics of the angle of attack vanes, but it is thought that the effect of a change of vertical wind more rapid than 1Hz on the aircraft's motion with a period of 4~5 seconds would be small.

Wind condition (Vertical and Longitudinal direction)

1 Time starts at 1056:56JST. (Scale 46 indicates 1057:42JST.)

2 Solid lines indicate simulation value of wind

3 o marks show time history of ACMS data.



APPENDIX 3 Numerical Analysis of Aircraft Motion

1 Data and Technical Materials used for the Motion Analysis

(1) ACMS data

(2) DFDR data

(3) Aerodynamic model of the Boeing company's 747-400 training simulator

(4) Flight control system model of the Boeing company's 747-400 training simulator

(5) Thrust model from the Boeing 747-400 Performance Engineering Manual (CF6-80C2B1F)

(6) Moment of inertia and products of inertia around the aircraft's center of gravity

(7) Autopilot and Autothrottle operating modes and logic

(8) "Introduction of Aerodynamics" by Kankuro Kato, Akio Oya, and Kenji Ezawa (November 20, 1982, Tokyo University Press)

2 Assumption and Initial values for Numerical Simulation

(1) Assumptions

① The time difference of the ACMS data from the DFDR time was corrected by comparing the DFDR and ACMS vertical acceleration data.

② The period of the motion analysis was set to from 10:57:16, when the recorded data began to change from a stable descent condition, until 10:57:40, when large changes in the recorded data had almost stopped.

③ The aircraft was considered as a rigid body, with no elastic deformation.

④ Since changes in the lateral flight parameters and lateral control inputs were small, it was assumed that lateral motion and the effect of lateral control inputs on longitudinal motion could be neglected, and so only the aircraft's longitudinal motions and longitudinal control inputs were analyzed.

⑤ After estimation of the wind acting on the aircraft, it was assumed that the effect of vertical wind changes on the aircraft's motion was small, and only the horizontal wind components in Appendix 2 were considered.

⑥ The changes of atmospheric pressure, temperature and air density with altitude were set to be the same as in the Standard Atmosphere.

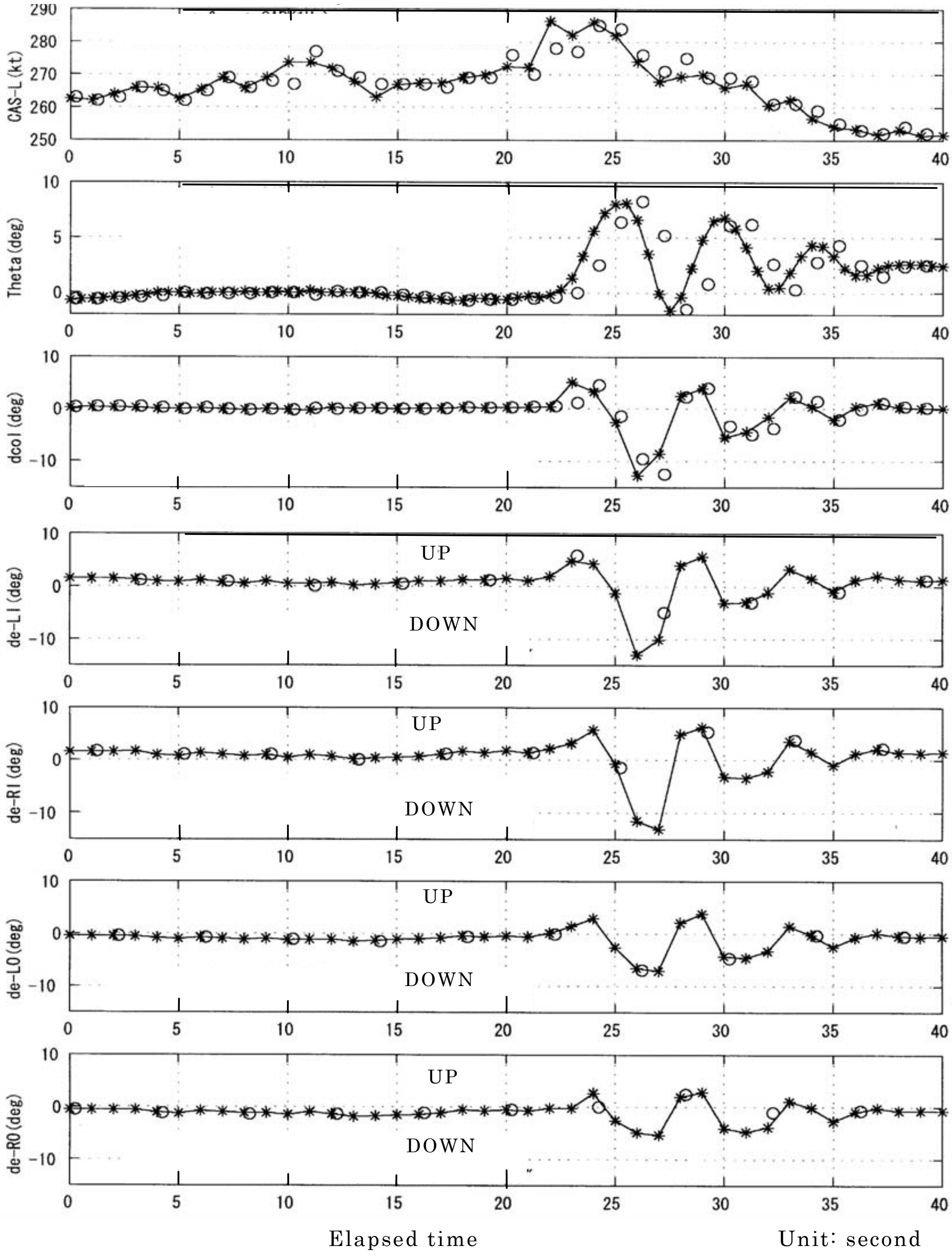
(2) Initial Trimmed Conditions (Initial Values)

The initial trimmed condition (initial values) for the numerical simulation were established by calculating the trimmed state with fixed values of true airspeed, pressure altitude, temperature, N1 (engine fan revolution speed), bank angle, true heading, aircraft weight and aircraft center of gravity obtained from the ACMS at 10:57:16, when the N1 values and CAS were most constant. The trimmed flight condition resulting from this trim calculation was almost coincident with the real flight condition (ACMS data), and was set as the initial trimmed flight condition.

The symbols used in the motion analysis and numerical simulation are shown as follows:

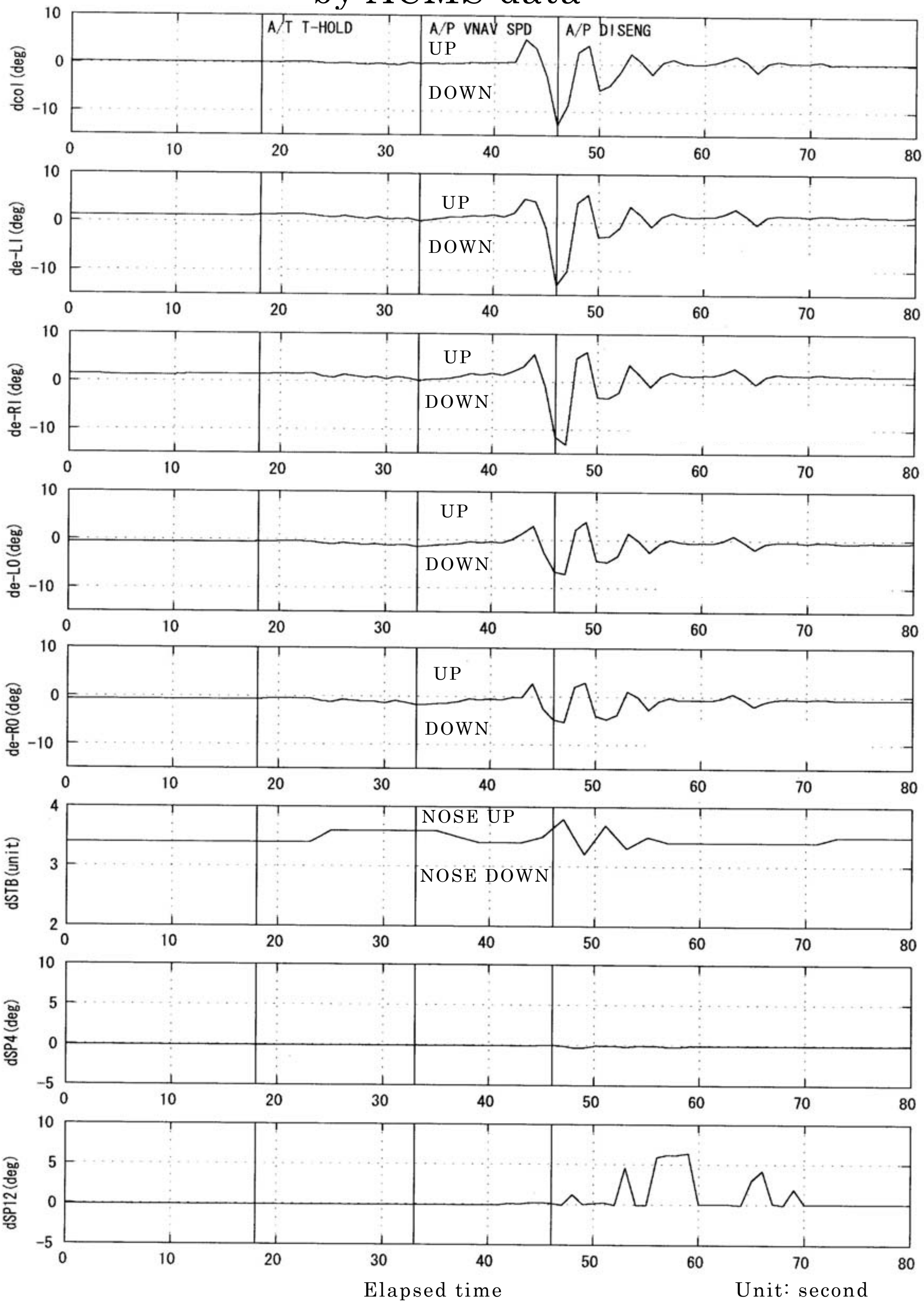
Item	Symbol (Text)	Symbol (Chart)	Unit
Corrected Airspeed	CAS	CAS-L	Kt
Angle of attack (AOA sensor output)	AOA	AOA-L	deg
Pitch Attitude Angle	Θ	Theta	deg
Pitch Rate	q	q	deg/s
Column Steering Angle	δ col	dcol	deg
Left Inboard Elevator Angle	δ e-LI	de-LI	deg
Right Inboard Elevator Angle	δ e-RI	de-RI	deg
Left Outboard Elevator Angle	δ e-LO	de-LO	deg
Right Outboard Elevator Angle	δ e-RO	δ e-RO	deg
Horizontal Stabilizer Deflection	δ STB	dSTB	unit
No. 4 Spoiler Surface Angle	δ SP4	dSP4	deg
No. 12 Spoiler Surface Angle	δ SP12	dSP12	deg
True Airspeed	TAS	TAS	kt
Vertical Acceleration at Aircraft CG position	NzCG	NzCG	g
Vertical Acceleration at IRU position	NzIRU	NzIRU	g
Altitude (Pressure Altitude for ACMS)		H	ft
Left Inboard Elevator Angle (Numerical simulation)		De-IN	deg
Left Outboard Elevator Angle (Numerical simulation)		De-OUT	deg

Figure A　Comparison between DFDR data and ACMS data



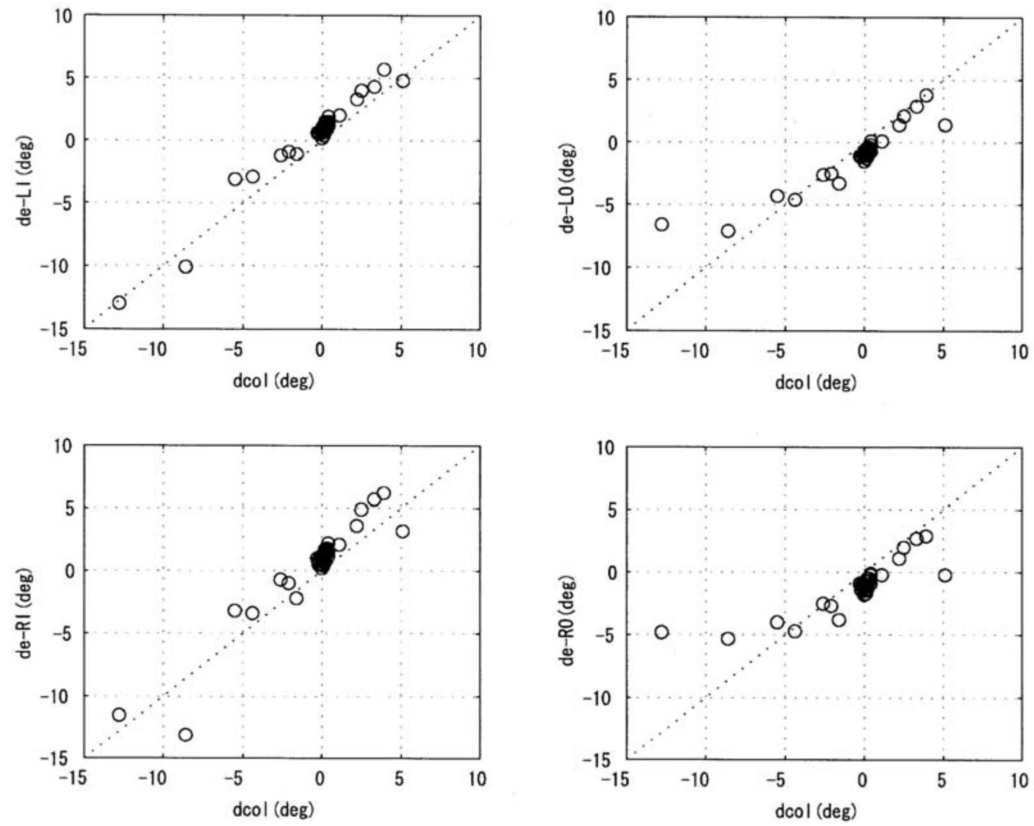
(Note)
1　Time starts at 1057:16JST. (Scale 26 indicates 1057:42JST.)
2　＊marks show ACMS data.
3　o marks show DFDR data.

Figure B Movement of longitudinal control system by ACMS data



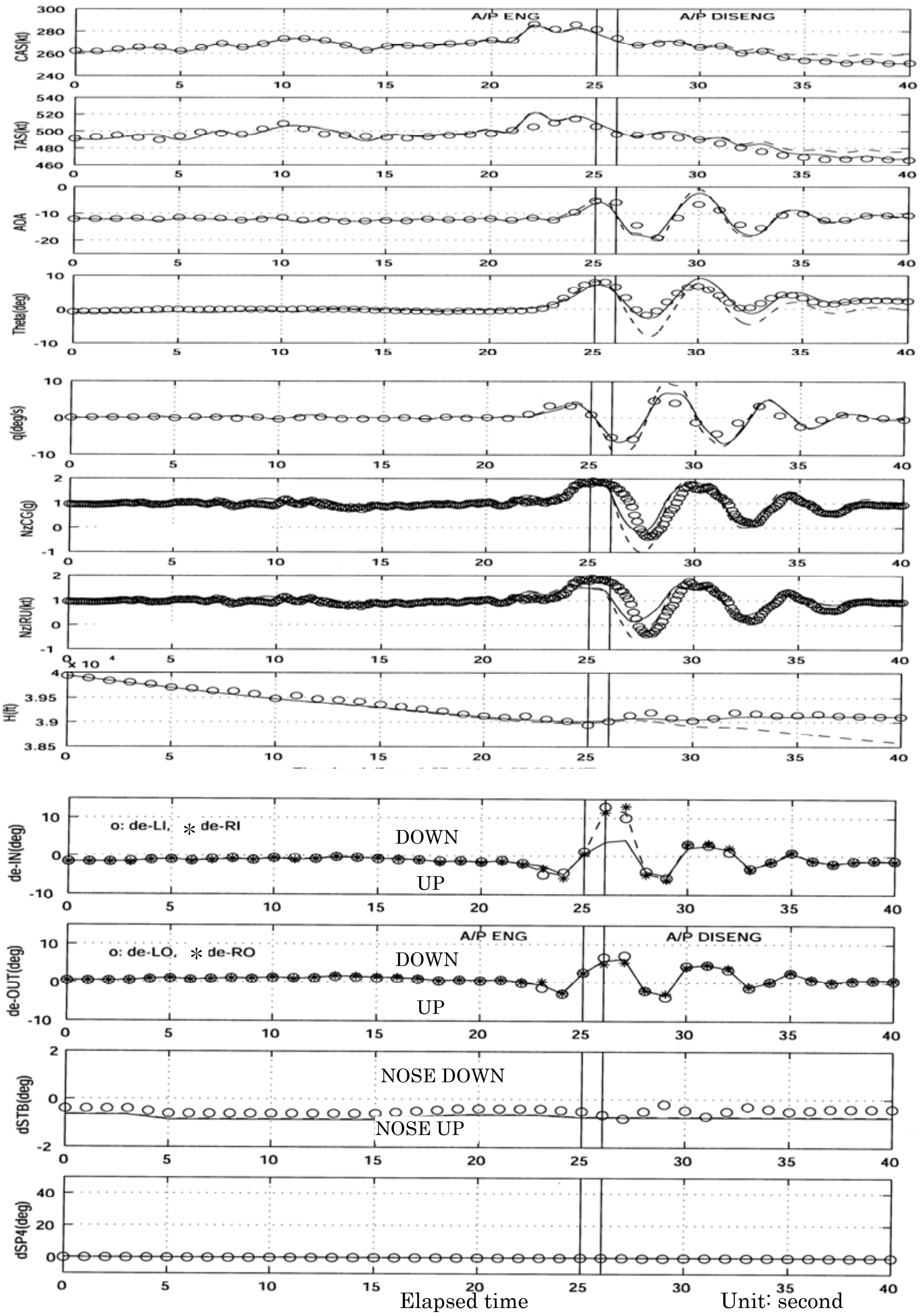
(Note)
1 Time start at 1056:55JST. (Scale 46 indicates 1057:42JST)
2 The sign of direction of elevator and horizontal stabilizer in this figure is inverse to that from figure D to figure I.

Figure C　Relation between Control Column Position Angle(dcol) and each Elevator Angle(de)



(Note)　Black parts in the figure are due to overlapping of data.

Figure D Comparison of Influence between Inboard and Outboard Elevator



(Note)

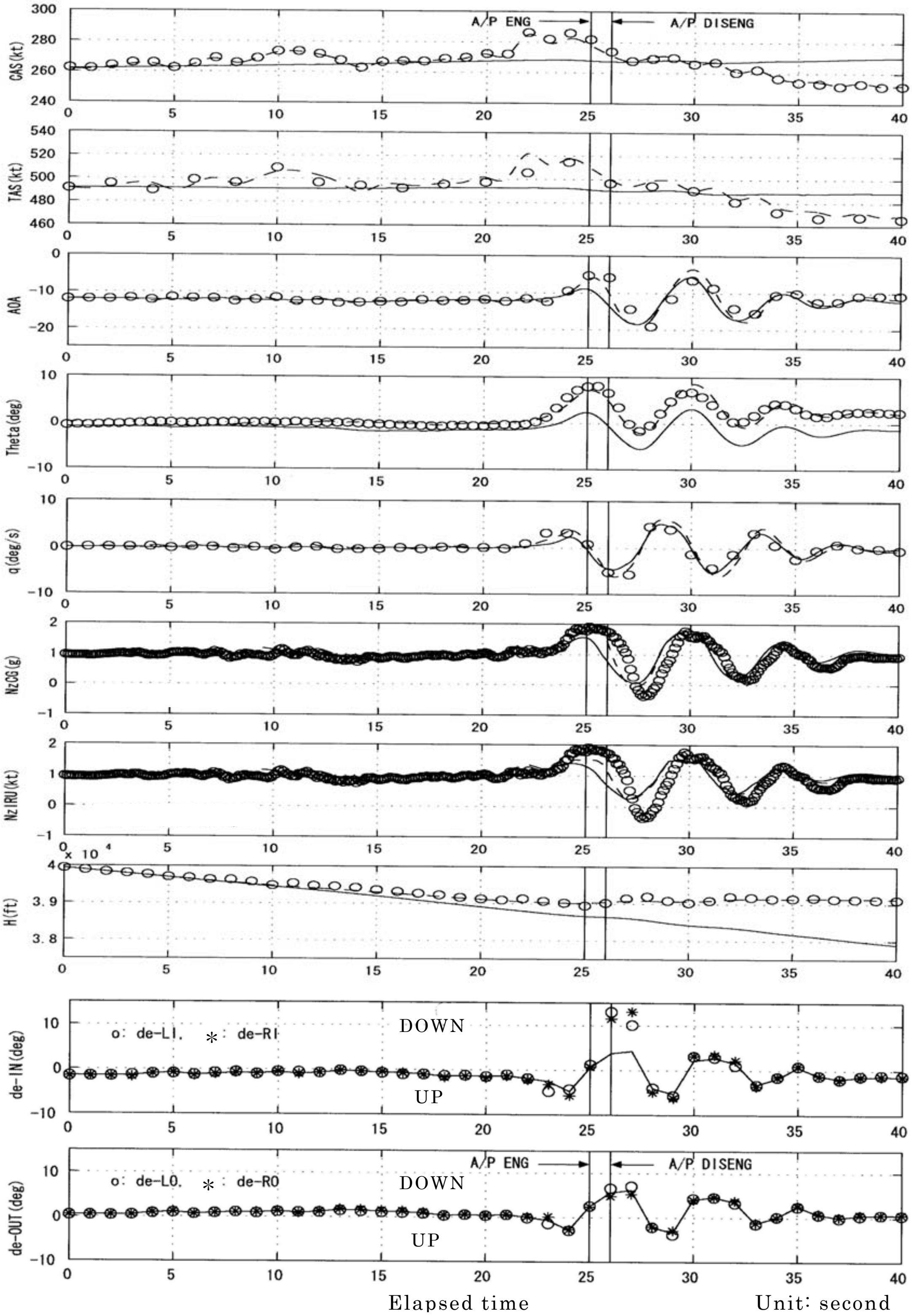
1 Time starts at 1057:16JST. (Scale 26 indicates 1057:42JST.)

2 Solid lines indicate simulation value in a case assuming that outboard elevator angle in ACMS data are the movement of both inboard and outboard elevators.

3 Broken lines indicate simulation value in a case using ACMS data as the movement of each inboard and outboard elevator.

4 ＊marks and O marks show time history of ACMS data.

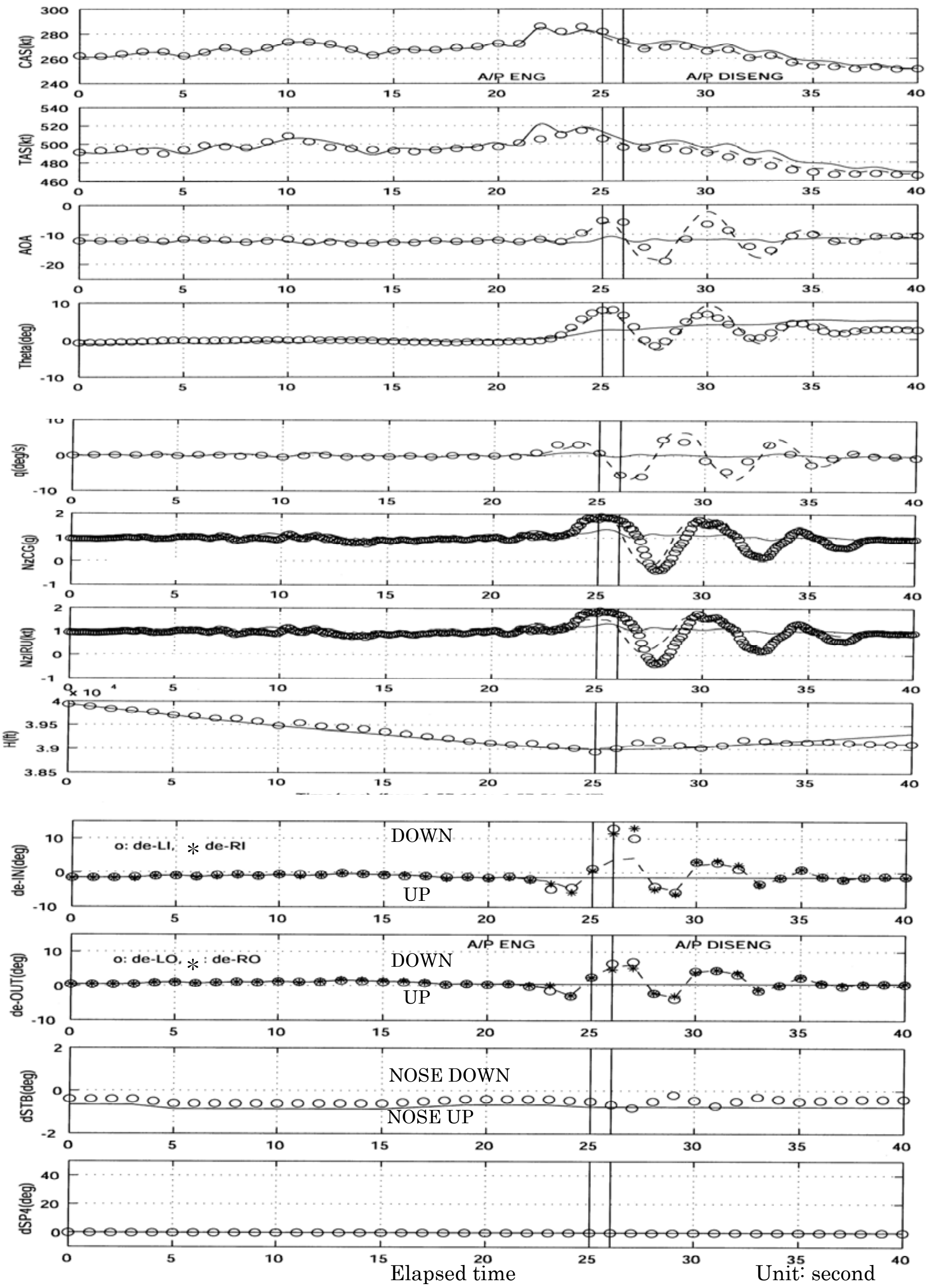
Figure E　In case assuming that there are no winds.



Elapsed time　　　　　　　　Unit: second

(Note)
1 Time starts at 1057:16JST. (Scale 26 indicates 1057:42JST.)
2 Solid lines indicate simulation value in a case assuming that there are no winds.
3 Broken lines indicate simulation value in a case assuming that outboard elevator angle in ACMS data are the movement of both inboard and outboard elevators. (It is same that solid lines indicate in figure D)
4 ＊marks and O marks show time history of ACMS data.

Figure F　Effect of Elevator fixed



(Note)

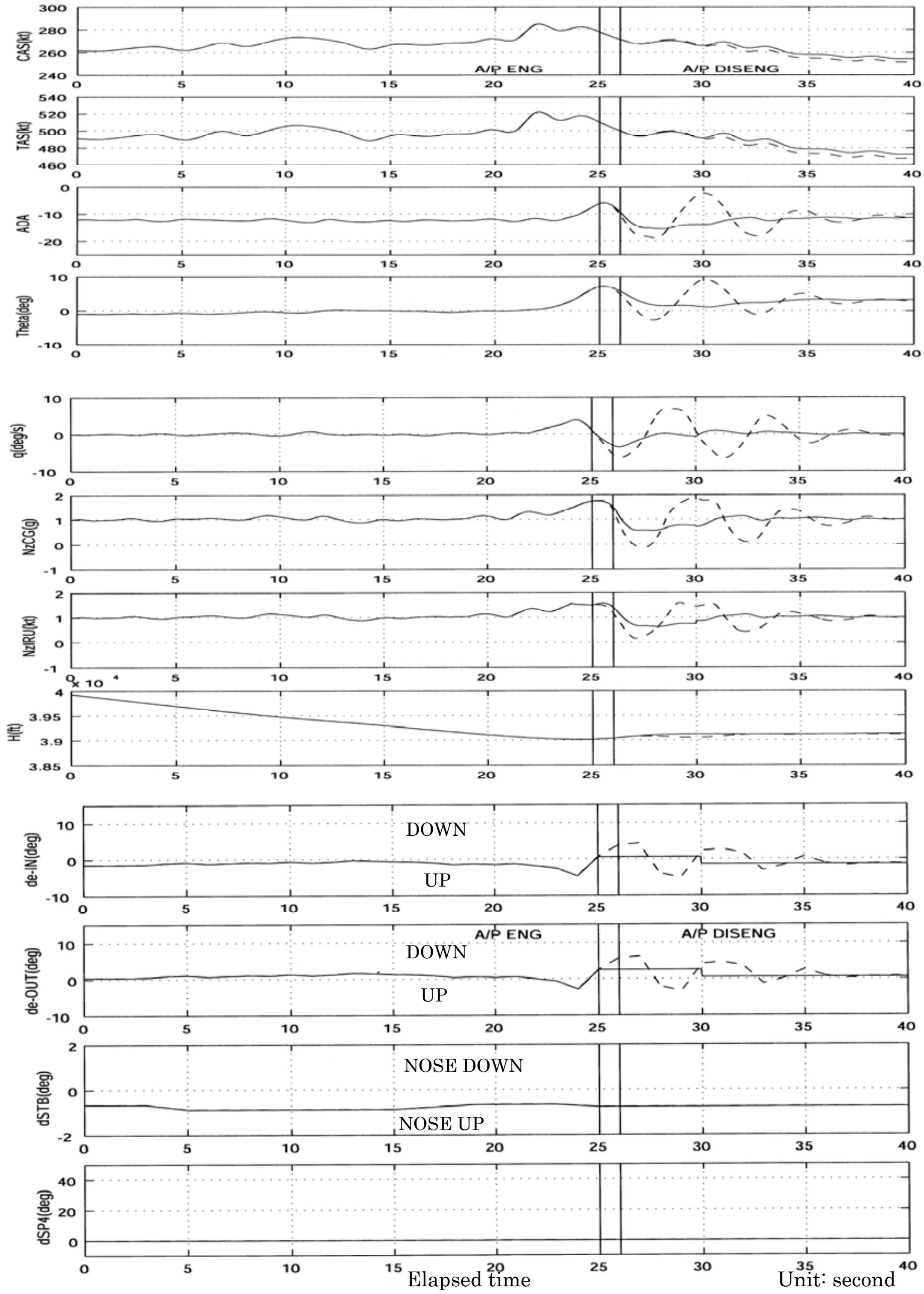
1 Time starts at 1057:16JST. (Scale 26 indicates 1057:42JST.)

2 Solid lines indicate simulation value in a case that elevator angle are fixed at the position before the windshear encounter(at 1057:36JST).

3 Broken lines indicate simulation value in a case assuming that outboard elevator angle in ACMS data are the movement of both inboard and outboard elevators. (It is same that solid lines indicate in figure D)

4 ＊marks and O marks show time history of ACMS data.

Figure G　An Example of elevator control to keep pitch movement in smaller amount



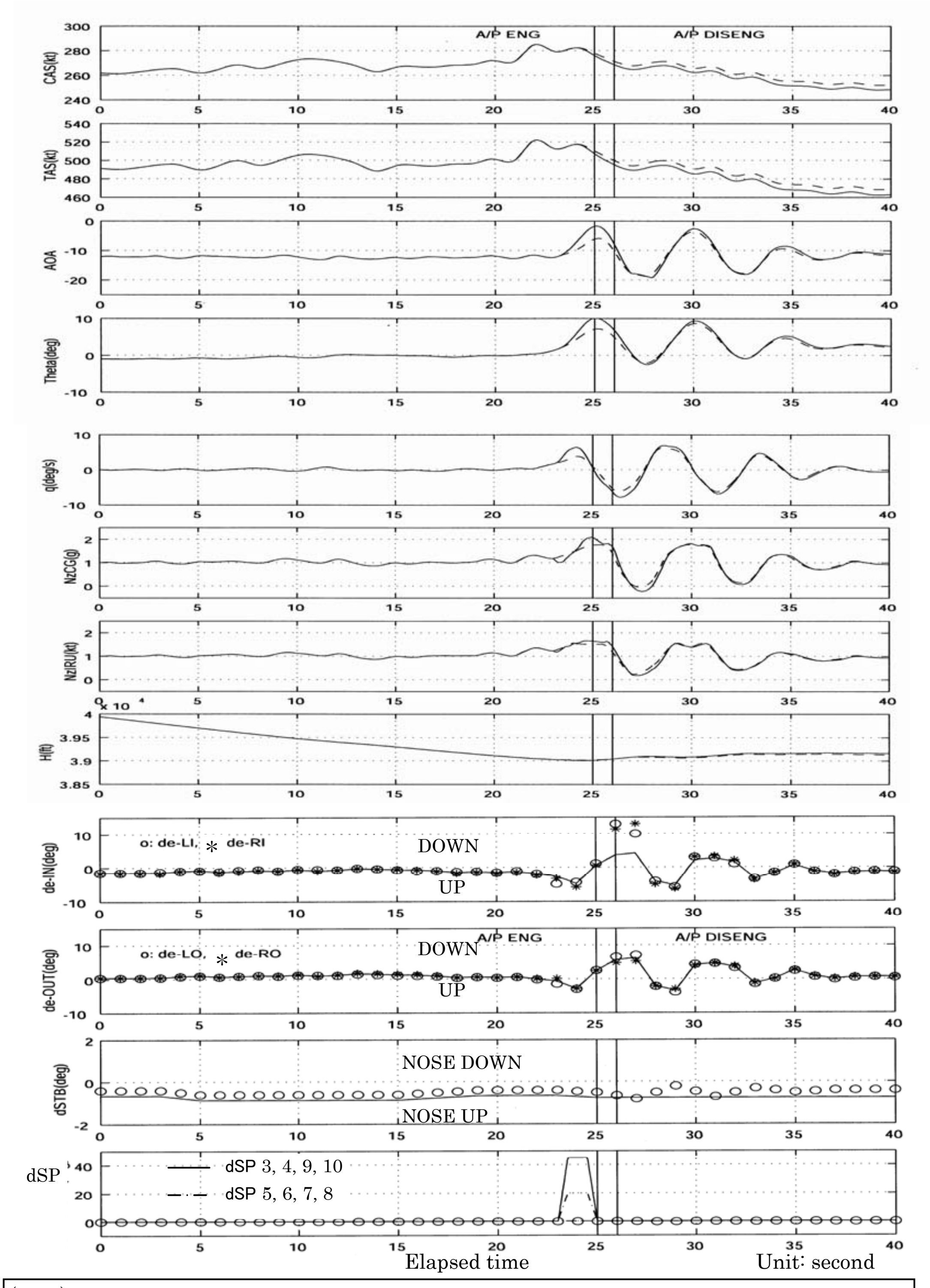
(Note)

1 Time starts at 1057:16JST. (Scale 26 indicates 1057:42JST.)

2 Solid lines indicate simulation value in a case that elevators are used upward to suppress speed increase, then pitch down is applied to return pitch to it's original value and after the control, elevators are fixed for 5 seconds, then returned to it's original position.

3 Broken lines indicate simulation value in a case assuming that outboard elevator angle in ACMS data are the movement of both inboard and outboard elevators. (It is same that solid lines indicate in figure D)

Figure H　In case that Speed brakes are used for 1 second.



(Note)

1 Time starts at 1057:16JST. (Scale 26 indicates 1057:42JST.)

2 Solid lines indicate simulation value in a case assuming that speed brakes are used for 1 second.

3 Broken lines indicate simulation value in a case assuming that outboard elevator angle in ACMS data are the movement of both inboard and outboard elevators, and speed brakes are not used. (It is same that solid lines indicate in figure D)

4 ＊marks and o marks show time history of ACMS data.

APPENDIX 4　Estimated Vertical Acceleration in Cockpit and Aft Cabin

1　Estimation method

(1) Assumptions

The aircraft is a rigid body. (No deformation.)

There is no relative time skew among the recorded data parameters.

(2) Data used

Aircraft attitude: Pitch (2Hz), Roll (2Hz), and Heading (1Hz)

Acceleration: Longitudinal (1Hz), Lateral (1Hz), and Vertical (8Hz)

(3) The angular velocity and angular acceleration were computed at the same time values based on spline interpolation of attitude angles after matching all data with vertical acceleration, spline interpolation at 8Hz, and synchronizing the data.

The acceleration at arbitrary locations (8Hz) was computed from the ACMS acceleration data by correcting for the effects of rigid-body motion using the aircraft angular velocity and angular acceleration.

2 Result

The estimated vertical accelerations that arose when the pitch angle changed are showed in the chart for the cockpit, seat row 43, seat row 47, and the aft most lavatory of the aft cabin.

The experienced vertical acceleration depends greatly on longitudinal position along the aircraft, and the amplitude increases as the position moves further aft. Compared with the maximum amplitude recorded by the ACMS recordings of around 2.3G measured at close to the center of gravity, it was 2.6G at seat rows 43 and 47, and 3G at the aft most lavatory of the aft cabin. On the other hand, the maximum amplitude in the cockpit was small, around 1.6G.

Further, regarding negative acceleration conditions, under which objects that are not fixed except in the cockpit may float up, the peak negative values attained were around –0.43G at seat rows 43 and 47 and a little less than –0.9G at the aft most lavatory compared with the peak value in the ACMS recording of –0.37G. If the distance of objects not fixed from the ceiling was 1.5–2m, negative acceleration would have caused objects to contact the ceiling at a speed of 4m/s at seat rows 43 and 47, and at 5m/s in the aft most lavatory. (Assuming the effect of air resistance on the objects is negligible. A speed of 5m/s corresponds to being dropped from a height of 1.3m.)

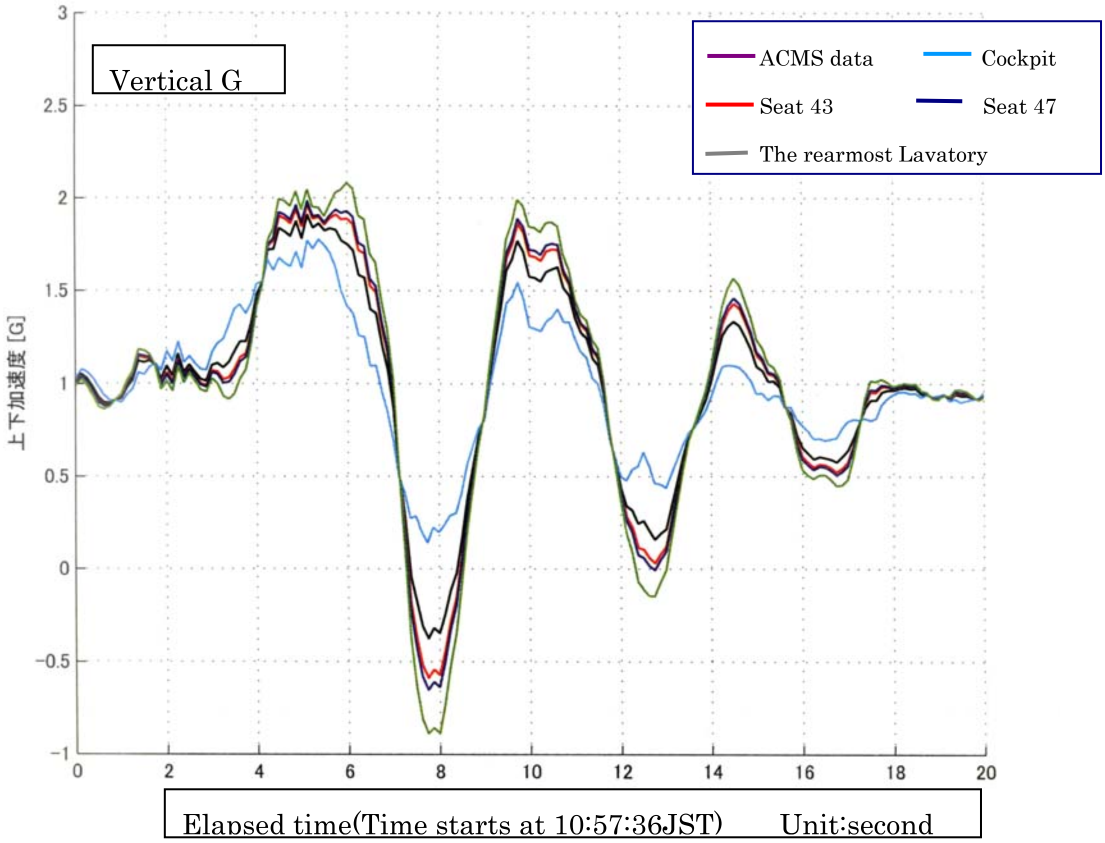
3 Estimation of Error in the Computation

(1) Data synchronization error

The recorded values of vertical acceleration during the changes of pitch angle and the synchronization accuracy of the recorded pitch angle data are important, but assuming no relative time skew between pitch and vertical acceleration, both parameters had a phase difference with the pitch angle oscillation of 0.22 seconds. This coincides almost exactly with the estimated value of 0.2 seconds by linear kinematics' analysis, and so the assumption is deemed to be proper. Consequently, the error in the vertical acceleration estimate due to synchronization error is deemed to be sufficiently small as to be negligible.

(2) Error due to elastic deformation of the fuselage

Unlike the assumption, a real fuselage is not a rigid body but is subject to elastic deformation by aerodynamic forces, etc. that arise due to turbulence and the effects of applying control forces. Because the accelerations caused by elastic deformation of the aircraft vary according to the aircraft model and flight conditions, they are difficult to estimate accurately. Using a simplified method to estimate vertical acceleration due to elastic deformation, it was found that it was possible to reach around ±0.2G at the end of the fuselage, and errors of this magnitude may be included in the vertical acceleration estimates.



APPENDIX 5 General Overview of Operations Information No. 400-177 (Dated Jan. 09, 2003)

"Stick Shaker Activation at High Altitude"

When the stick shaker activates, the basic procedure is to carry out the Approach to Stall Recovery Procedure to affect a recovery. However, if there is a speed margin in atmospheric turbulence, the autopilot is operating normally and the stick shaker is not activating continuously, it is not necessary to disengage the autopilot. If the stick shaker activates continuously, speed does not recover, and attitude recovery is insufficient, quickly disengage the autopilot and carry out the recovery.

1 Stick Shaker Activation due to Turbulence

On the Boeing 747-400, stick shaker activation is computed using AOA, TAS, and pitch rate.

During turbulence, especially in strong up/down drafts, even though there may be an adequate margin above minimum speed, the stick shaker may activate if the AOA momentarily becomes large.

2 Responses on Stick Shaker Activation

If the stick shaker activates, carry out the above procedures.

In order to maintain a safe speed, it is important to control attitude rather than altitude. In a turn, it is necessary to return to wings level. It is desirable to keep in mind the basic pitch/power relationship during operation.

When disengaging the autopilot and recovering by manual flight, it is necessary to carry out pitch maneuvers finely, slowly and smoothly, especially considering maneuvering stability in high altitude.

3 Maneuvering Characteristics at High Altitude

When applying force to the control column to bring about a pitch change, G is induced by the pitch rate. There are considerable differences in the amount of force required to produce a given G at low altitude and high altitude.

If the same control input is used at high altitude as at low altitude, since the air density is low and the damping of aircraft motions is small at high altitude, a large G results.

At high altitude, it is necessary to use small, slow and fine pitch control inputs.

APPENDIX 6 Summary of Operations Information No. 400-184 (Nov. 10, 2003)

"Response to Overspeed (Vmo/Mmo)"

If approach to Vmo/Mmo is anticipated, a suitable speed with an adequate margin should be established early, and it is important to monitor speed carefully.

If even regardless of this Vmo/Mmo is approached or exceeded, it is very important to use the Auto Flight System (AFS) effectively in attempting speed recovery by inputting an even lower speed and changing to V/S, ALT Hold etc. Take care to apply speed brake controls slowly.

Because AFS is designed to make speed recovery slowly, in case of rapid wind changes, speed may momentarily exceeded Vmo/Mmo. Even in such cases, when it is judged that the AFS can affect speed recovery, the AFS should continue to be used, and there is no need to reduce speed by manual control.

However, if it is judged that the AFS is not responding according to the pilot's intention, or that its response is inadequate, disengage the autopilot and disconnect the Autothrottle, and reduce speed by manual control without panic. Take care to apply manual pitch control and speed brake control carefully and slowly.

1 Preventing approach to Vmo/Mmo

When using ECON speed operation close to Vmo/Mmo during climb, cruise, and descent, if there is a headwind increase due to rapid wind change or a drop in tailwind, there is a highly probability that speed will approach Vmo/Mmo. In case such events are anticipated or if a speed increase trend is recognized, it is important not to stick to ECON speed but to establish an appropriate speed with margin Vmo/Mmo early and to monitor speed carefully.

2 When Vmo/Mmo is approached or exceeded ＜Speed Recovery by Auto Flight System＞

A. Even if a speed with sufficient margin is established as in section 1, if Vmo/Mmo is approached due to unexpected wind changes etc. it is important to try not to exceed Vmo/Mmo by using the following combinations of controls to effectively reduce speed early.

(a) Reduce thrust. (Manually overriding the Autothrottle is permissible, but it is necessary to take care not to close the throttles excessively.)

(b) Command a lower speed to the Auto Flight System.

(c) Change to a basic mode such as V/S or ALT Hold.

(d) Use speed brake

B If there is no time to carry out the above actions due to a rapid speed increase and Vmo/Mmo is exceeded, it is effective first reduce thrust and to use the speed brake.

Further, if it is necessary to minimize pitch changes during recovery process, it is more suitable to use basic modes rather than VNAV/SPD and FLCH modes which control speed by pitch.

Note: If there is a sudden increase in speed during descent, if FLCH mode is used then it is necessary to pay careful attention to pitch attitude since the aircraft will continue to pitch up until proper rate of speed reduction is obtained.

C Speed brake should be operated smoothly and slowly to avoid rapid changes in pitch moment, and further, pitch down moment on retraction should be taken into account to avoid entering overspeed again.

D It is possible that will be Vmo/Mmo exceeded slightly while carrying out the above or due to rapid wind changes, but even in such cases, monitor the airspeed continuously without panicking. Speed recovery can be accomplished using the AFS in almost all cases.

Further, because VNAV/SPD, V/S mode, etc. are designed not to make large responses considering passenger comfort, speed recovery may be perceived as slow. However, since not only may the desired effect not be obtained if the pilot overrides the autopilot while it is engaged, but unexpected aircraft motion may result if the autopilot should disengage while force is being applied to the control column, these operations are prohibited by the OM.

3 If speed decrease is not seen even then

In the event that even when speed recovery using the AFS is attempted it is judged that the AFS does not respond according to the pilot's intention or that the response is inadequate, disengage the autopilot and disconnect the Autothrottle and maneuver according to the flight phase.

Descent: First, confirm thrust idle and pitch up smoothly. Use speed brakes in addition if necessary.

4 Remarks on Manual Control

When pitching up by manual control or using speed brake, use due care to ensure that the aircraft's attitude not to change rapidly. Because pitch control column forces are light at high speed, especially at high altitude, it is necessary to apply control carefully.

5 About Vmo/Mmo

As stated in the AOM, Vmo/Mmo is “a speed that should not be exceeded intentionally in any flight phase”. Further, the Airworthiness Standard Manual states that “Vmo/Mmo shall be established as a value sufficiently lower than the maximum speed of design diving speed of Vd/Md, and such that it shall be almost impossible to exceed the maximum speed inadvertently in flight.”

Consequently, because it is permitted to momentarily exceed the design Vmo/Mmo in the case of rapid wind changes, etc, it is essential to respond coolly in such cases without panic.

6 Other Information

The AFS implements some functions related to speed control, and these are designed not to make large responses in consideration of passenger comfort etc. As a result, the time required for speed recovery may be greater than the pilot’s intention.