AIRCRAFT ACCIDENT INVESTIGATION REPORT

Cathay Pacific Airways
Lockheed L 1011-385-1, VR-HOC
New Tokyo International Airport
March 24, 1990

Aircraft Accident Investigation Commission
Ministry of Transport

March 27, 1992

(Tentative Translation from Original in Japanese)

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ATTENTION

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

This Report on Cathay Pacific Airways VR-HOC has been prepared by Aircraft Accident Investigation Commission in accordance with Article of Aircraft Accident Investigaation Commission Establishment Law.

1 Progress and Process of Aircraft Accident Investigation

1.1 Summary of the Aircraft Accident

VR-HOC, a Lockheed L1011-385-1, of Cathay Pacific Airways which departed Hong Kong International Airport as its scheduled flight 508 on March 24, 1990, made a hard landing on Runway 16 of New Tokyo International Airport about 0512 hours Universal Co-ordinated Time (1412 hours Japan Standard Time), in which the rear spar of the wing root and its vicinity of the left wing were damaged and the fuel flowed out from No. 1 fuel tank. Fire did not occur.

On board the aircraft were a crew of 18 and 283 passengers, a total of 301 persons, and in the emergency evacuation effected, two passengers were seriuosly injured.

1.2 Outline of Aircarft Accident Investigation

1.2.1 Notification and Organization

1.2.1.1 Upon receipt of notification from Minister of Transport of the ocurrence of the accident on March 24, 1990, the Aircraft Accident Investigation Commission appointed the investigator-in-charge and five other investigators to make investigation of this accident.

1.2.1.2 The following three technical advisers were appointed for the analysis of specialized area relating to the investigation of this accident (titles are as of the date of appointment):

(1) For investigation of damage to airframe structure and analysis of strength

Kousaburo Yamane

Head, Damage Mechanism Lab.,
Airframe Division,
National Aerospace Laboratory, Science and Technology Agency

(2) For analysis of flight

Toshio Bando

Head, Flight Test Lab.,
Flight Research Division,
National Aerospace Laboratory, Science and Technology Agency

(3) For analysis of meteorology

Akira Nakayama

Former Professor, National Defense Academy
Defense Agency

1.2.1.3 Notification to related foreign governments and their participation in accident investigation

In accordance with Annex 13 to the Convention on International Civil Aviation, notification of the accident was made to Hong Kong, the state of registry of the aircraft, and to the USA, the state of manufacture of the aircraft.
An accredited representative of the Hong Kong Government and his advisers participated in the investigation. No notification was received on appointment of representatives from the USA.
Consultation was made with the Hong Kong Government for their comments as to the preparation of this accident investigation report.

1.2.2 Period of Investigation

March 25～28, 1990	Investigation at accident site
March 28, 1990～August 7, 1991	Investigation and analysis of damage to airframe, and flight
March 27～Oct. 25, 1990	Transcription of readouts of Cockpit Voice Recorder (including work by Hong Kong representatives)
March 27, 1990～August 7, 1991	Transcription & analysis of readouts of Flight Recorder (including work by Lockeehed USA)
April 2, 1990	Special flight-inspection on ILS, PAPI, etc. of New Tokyo International Airport
May 25, 1990～August 7, 1991	Investigation & analysis of meteorology
June 6, 1990	Flight over the vicinity of New Tokyo International Airport for study of its topography
June 28, 1990	Investigation on flight performance by a simulator of L1011

1.2.3 Hearing of comments of cause-related personnel

Hearing via the Hong Kong Government of comments of the flight crew as personnel related to the probable causes was made.

2 Factual Information

2.1 History of Flight

VR-HOC, a Lockheed L1011-385-1, of Cathay Pacific Airways was to depart Hong Kong International Airport for New Tokyo International Airport (hereinafter referred to as "Narita Airport") as its scheduled flight 508 on March 24, 1990, with a flight crew of three, 15 cabin attendants and 283 passengers, 301 persons in total on board. The captain reported to the dispatcher office of the company 0030 hours Universal Co-ordinated Time (hereinafter, unless otherwise noted, time is represented by Universal Co-ordinated Time as UTC), and received the pre-flight briefing. According to the weather forcast he received in the briefing, the wind forcast at Narita Airport was as much as 220 deg/12 kt occasionally 15～27 kt at the estimated time of arrival.
The flight plan of the aircraft filed to Hong Kong International Airport Office of Civil Aviation Department was as follows:

Flight Rule: IFR, Destination: Narita Airport, Route of Flight: Alfa One (A1), Cruising Altitude/TAS: Flight Level 290/504 kt, Estimated Time Enroute: 3 hours 28 minutes, Alternate Airport: Tokyo International Airport (Haneda)

With a clearance of flight route Alfa One given by Hong Kong Area Control Center, the aircraft took off Honkong International Airport about 0138 UTC. About 0430 UTC, after passing Kushimoto VORTAC at Flight Level 330, the aircraft monitored "Information ALFA (0417 UTC)" broadcast by Narita ATIS (Automatic Terminal Information Service), and thereby knew that the active runway at Narita is 16 and wind 230 deg/18 kt with maximum 29 kt and minimum 8 kt, and also that a moderate turbulence was reported less than 1,000 ft on the final course to runway 16 and a wind shear in the middle of the runway.
Narita ATIS "Information Brabo (0430 UTC)", which the aircraft received subsequently, showed that the wind was variable between 210 and 270 degress with a velocity of 23 kt, maximum 38 kt and minimum 9 kt.

After passing Miyakejima VOR/DME, the aircraft was cleared by Tokyo Area Control Center descent to 13,000 ft and was instructed to change frequency to Narita Terminal Control (hereinafter referred to as "Approach Control") shortly before reaching Position Reporting Point Mama, until which time the flight had been normal with no turbulance encountered.
The aircraft was given a radar navigational guidance by Approach Control to the final approach course of "Narita ILS Runway 16" Approach Procedure almost on the usual arrival route, with lower altitudes cleared.

According to Narita ATIS "Information Charlie (0448 UTC)", which was monitored by the aircraft in descent, the wind was 210 variable 270 deg/23 kt, maximum 38 kt and minimum 9 kt; while, according to "Information Delta (0500 UTC), the wind was 200 variable 270 deg/22 kt, maximum 38 kt and minimum 11 kt. Through the Information Charlie and Delta, the crew monitored a pilot report of a Boeing 747 that they had encoutered a loss in airspeed of about 20 kt due to wind shear at 700 ft on the final approach course to Runway 16.

According to the flight crew,

During descent they occasionally entered clouds down to 15,000 ft, but therebelow they had no cloud at all, maintaining visual meteorological conditions with smooth air. However, since, as indicated in the Narita ATIS information, severe conditions could be expected with intense crosswind and turbulence at the time of approach and landing, they decided to continue approach, paying special attention to the succeeding wind information.

Turbulence began about after passing 3,000 ft, and the aircraft continued to be in a moderate turbulence, until it encountered a severe turbulence shortly before touch-down.

With a clearance to descend to 2,000 ft and to make a "Narita ILS Runway 16" Instrument Approach (see Attached Fig. 1), the aircraft commenced the approach. The gear was extended at about 1,700 ft and the flap was set at a landing flap angle of 33 degrees at about 1,500 ft, and the captain initiated approach by manual control at about 1,400 ft after passing the outer marker, disengaging the auto-pilot and the auto-throttle.

As to details up to the landing, the flight crew stated as follows:

The aircraft, on approach to landing, began the approach, setting the initial targetted approach speed at 162 kt on the basis of the landing reference speed (VREF) of 142 kt corresponding to the landing weight of about 360,000 pounds at the flap angle of 33 degrees as well as the surface wind given.

When the aircraft reported passing the outer marker to Narita Airport Control Tower (hereinafter referred to as "Tower"), the wind information of 230 deg/14 kt was given by the Tower together with a landing clearance.

The captain and other flight crew had already Runway 16 in sight and they thought from the wind information that "Good, I like it"; and when passing about 650 ft, they reconfirmed the Tower on the wind and were given new information of 230 deg/14 kt with a maximum of 26 kt, and continued approach to land.

During descent from about 500 ft in a moderate turbulence, a soft warning sound "glide slope" of the GPWS (Ground Proximity Warning System) was heard repeatedly 7 times for about 10 seconds (for a period from about 400 ft to about 280 ft in height) from about 7 seconds short of the middle marker. Although the captain tried to correct for the approach path by increasing power, the altitude of the aircraft still remained somewhat lower than normal. The runway, however, had been in sight, the height was not impediment to normal landing. After passing the approach end of the runway, and immediately after the flight engineer made a call of "60 feet" on the radio altimeter, the aircraft was suddenly brought down and landed.

About 0511:49 UTC, the aircraft made the first touch-down near on the center line of the runway and about 230 meters inside of the approach end of the runway, bounded about two seconds, and touched down again and made a landing roll on the runway, being decelerated by the thrust reverser and the brakes.

The aircraft vacated the runway to Taxiway Alpha 8 by the Tower's instruction, and after the frequency was changed to the Tower's Ground Control Position (hereinafter referred to as "Ground Control"), the copilot reported to the Ground Control that the aircraft encountered a severe turbulence shortly before landing. Although the aircraft was directed by the Ground Control to taxi to the parking spot via Taxiway Mike One, they could not comply with the instruction because of their unfamiliarity with the routing, and taxied straight into Taxiway Romeo. The Ground Control, who observed it, requested the aircraft to make a stop; and the aircraft came to a stop about 0514:30 UTC at the crossing of Taxiway Romeo and Taxiway Uniform, with a magnetic heading of about 027 degrees. (see Attached Fig. 2)

The captain instructed the flight engineer to start the APU (Auxiliary Power Unit) and decided to stop engines, judging the report he received during taxing from a cabin attendant to the effect that air smelled of fuel within the cabin; the report from the flight engineer that both the low pressure warning lights of the two fuel pumps of No.1 fuel tank had become lit; and the advice given by the Ground Control immediately after the aircraft was brought to a stop that "Looks like oil leaking" and "Stop your engines". Furthermore, monitoring a transmission from another aircraft to the Ground Control that smoke was coming out of the left hand under-carriage of the aircraft, about 0515:30 UTC the captain instructed the copilot to contact the Ground Control and request the dispatch of fire services. (see Attached Fig. 2)
Thereafter, the captain, who observed a considerable amount of fuel leaking out on the ground to the left of the aircraft, requested again dispatch of fire trucks, and, under a judgement that an emergency evacuation be exercised, stopped all engines, and directed cabin attendants to effect an emergency evacuation from the right side doors of the aircraft.

The right side emergency exits R1, R2, R3 and R4 doors as well as the left side emergency exit L1 door were opened, but the escape slide/raft (hereinafter referred to as "escape slide") of R3, R4 and L1 could not be used due to the strong wind, and R1 escape slide became also unusable

at the time about 100 persons had escaped thereby. Therfore, the remaining passengers and part of cabin attendants escaped to the ground through R2 escape slide. During the evacuation, two passengers from R2 escape slide were seriously injured by bone fructure.
The captain, the copilot and the remaining several cabin attendants evacuated thereafter from the left side emergency exit L1, using a maintenance ladder provided by the ground crew.

The senior controller, on duty at that time engaged in supervising the positions, who received from the controller on the ground control position the report that the aircraft came to a stop because of oil or fuel leakage and the situation was unusual, decided to suspend take-off and landing of aircraft succeeding to JAL flight 007 already on approach (landed about 0518 UTC). He made a coordination with related units on the runway closure, and observing the aircraft began an emergency evacuation, reported about 0518:30 UTC the location where the aircraft stopped and facts on the oil or fuel leakage to the Control Room of the Fire Station of the New Tokyo International Airport Authority (hereinafter referred to as "Airport Authority"), and requested them to provide the fire fighting services.
The Control Room who received the request issued a mobilization order about 0519～0520 UTC using the automatic broadcasting system capable of simultaneous broadcasting, whereby two fire fighting trucks, two ambulances, four water tank trucks and one crash rescue truck were dispatched from the Fire Station and its satellites to the site under the direction of the commander on duty of the day. Another fire fighting truck which had been heading for a parking lot in the terminal area on another mission was also hurried to the site by the instruction of the commander on duty.

It was about 0523 UTC that the fire fighting and rescue vehicles arrived at the site, and a fire fighting truck immediately exercised fire protection measures by using foam chemical extinguisher. According to the commander, escape from the aircraft had almost completed when they arrived, but five or six persons were still in evacuation.

Seven out of injured passengers were transported to a hospital in Narita City, and other passengers and cabin attendants departed the site by limousines, about 30 passengers out of which were given first aid treatment by their wish at the hospital.

2.2 Injuries to Persons

Out of 301 persons on board of the crew and passengers, 2 passengers were seriously injured.

2.3 Damage to the Aircraft

2.3.1 Extent of Damage

The aircraft was substantially damaged.

2.3.2 Damage to the Aircraft by part

2.3.2.1 The rear spar of the left wing root and its vicinity
The rear spar of the left wing root and its vicinity were fractured and fuel leaked out from No.1 fuel tank. (see Attached Figs. 4 and 5, Photos. 1 and 2)

(1) Fracture of the left wing rear spar web at IWS (Inner Wing Station) 241
The left wing rear spar web was shear-fractured vertically along rivet holes of the stiffener attached to IWS 241. By this fracture the upper spar cap was fractured at the tip of the upper outboard fitting located slighltly nearer to the wing tip, causing a deformation of the upper skin in the vicinity. The lower spar cap was buckled upward at the tip of the lower outboard fitting.

(2) Buckling of the left wing rear spar web in the vicinity of IWS 300
The left wing rear spar web was buckled making its center at IWS 300, projecting backward, and a crack was found propagated and branched from its lower tip upward to its 70 % height. On the wing tip side, about 15 cm from the crack at the lower tip of the web, another crack was also initiated on the vertical tang of the lower spar cap, from where the crack extended up to IWS 346 along the corner of the lower spar cap. As to the upper spar cap, a crack was initiated at the vicinity of IWS 290, somewhat nearer to the fuselage side than the crack of the spar web, up to IWS 346 along the corner of the spar cap, and the upper flange side was heaved about 7 cm upward together with the upper skin.

(3) Damage to the joint of the spar cap with the rear spar web
Rivets connecting the upper and the lower spar cap with the rear spar web were shear-fractured between the buckled portion of the rear spar web (refer to (2) above) and the shear-fractured portion near the root portion (refer (1) above)

(4) Damage to the fittings connecting wing and fuselage
Cracks were observed on the upper forward inboard fitting as well as on upper outboard fitting of the left wing rear spar.

(5) Damage to rivets on the upper skin of the left wing
Rivets were damaged, with their head coming off or floated, on the upper skin of the left wing between the rear spar and the front spar with a range from the wing root to IWS 346.

(6) Leak of fuel

Fuel within the tank leaked out from the cracks at the aft rear spar which constitutes part of No.1 fuel tank. The estimated leakage is approximately 7,000 pounds.

2.3.2.2 Landing Gear

There were found many small cracks on the foreward trunnion arm on the upper part of the cylinder of the left main gear. Four tires of the left main gear and two tires of the right main gear were damaged at the shoulder and the side wall. (not burst)

2.3.2.3 Fuel System

Cracks were found on the fuel feed tube and the cross feed tube installed on the outlet side of No.1 fuel tank booster pump.

2.3.2.4 Cabin

A pannel of the passenger service module on the ceiling above No. 39ABC seats was damaged.

2.3.2.5 Escape Slides

Out of escape slides which were deployed, R1 (the right foremost) and R4 (the right aftmost) were damaged.

R1 slide was peeled off for about 40 centimeters out of about 66 centimeters of bonded portion of the raft and the girt. R4 slide was peeled off for all of about 47 centimeters of the stuck portion, and it was connected to the aircraft by the rope which was installed to prevent separation from the airframe when used as raft.

2.4 Damage to Other than Aircraft

The pavement on which the fuel spilled out was about 11,000 square meters, of which about 1,200 square meters was repaired.

2.5 Crew Information

2.5.1 Flight Crew

Captain: Male, Aged 35

Airline Transport Pilot License No.0/3025/86
(issued by Hong Kong Government) acquired on March 12, 1986
Type Rating Boeing 747-200/300 acquired on March 12, 1986
(latest revision Oct. 22, 1988)
Lockheed L1011 acquired on May 31, 1989
(latest revision Dec. 29, 1989)

Instrument Rating acquired on March 12, 1986
(latest revision Dec. 29, 1989)

Class 1 Medical Certificate No.3025
issued July 25, 1989 (valid 12 months)

Total Flight Experience 5,269 hours 11 minutes
Flight Experience on the type 515 hours 49 minutes
Flight Time in last 90 days about 174 hours
Flight Time in last 30 days about 51 hours
Rest period before the flight about 15 hours 30 minutes

Note: The captain entered Cathay Pacific Airways Jan. 4, 1986. The route certificate between Hong Kong and Narita was obtained Nov. 27, 1989. He had landed 14 times at Narita Airport in the past.
He received the training, programmed by CPA, of Micro-burst Windshear on May 16, 1989 and of Emergency Procedures on the day before the accident occurred (March 23), and had received duly the other established scheduled trainings.

Copilot: Male, Aged 35

Airline Transport Pilot License No.[redacted]
(issued by Hong Kong Government) acquired on Sept. 22, 1989
Type Rating Lockheed L1011 acquired on Oct. 27, 1989
Instrument Rating acquired on Sept. 22, 1989
(latest revision Mrach 1, 1990)

Class 1 Medical Certificate No.[redacted]
issued April 17, 1989 (valid 12 months)

Total Flight Experience 12,909 hours 36 minutes
Flight Experience on the type 362 hours 50 minutes
Flight Time in last 90 days about 157 hours
Flight Time in last 30 days about 56 hours
Rest period before the flight about 17 hours

Note: The copilot entered Cathay Pacific Airways July 1, 1989. The route certificate between Hong Kong and Narita was obtained Nov. 27, 1989. He had landed 4 times at Narita Airport in the past.
He received the training of Micro-burst Windshear on Sept.1, 1989, and of Emergency Procedures on August. 3, 1989, and had received duly the other established scheduled trainings.

Flight Engineer: Male, Aged 32

Flight Engineer License No.3[redacted]
(issued by Hong Kong Government) acquired on Feb. 12,1990
Type Rating Lockheed L1011 acquired on Feb. 12,1990

Class 1 Medical Certificate [redacted]
issued June 21, 1989 (valid 12 months)

Total Flight Experience 2,064 hours 30 minutes
Flight Experience on the type 165 hours 03 minutes
Flight Time in last 90 days about 155 hours
Flight Time in last 30 days about 72 hours

Rest period before the flight about 21 hours

Note: The flight engineer entered Cathay Pacific Airways Oct. 28,1989.
His flight experience in the company is 165 hour and 03 minutes.
He had landed 14 times at Narita Airport in the past.
He received the training of Micro-burst Windshear on Jan. 1, 1990, and of Emergency Procedures on Oct. 30 and Nov. 1, 1989, and had received duly the other established scheduled trainings.

2.5.2 Cabin Attendants

A (Chief Purser) Female, Aged 38: positioned in evacuation at door-L1

joined Cathay Pacific Airways (CPA) Jan. 3, 1978
Latest training on emergency procedures Nov. 15, 1989
Total flight experience 3,200 hours 03 minutes (after Jan. 1, 1985)
Rest period before the flight about 158 hours

B Female, Aged 33: positioned in evacuation at door-L2

joined CPA March 1, 1980
Latest training on emergency procedures Oct. 18, 1989
Total flight experience 1,298 hours 16 minutes (after Jan. 1,1985)
Rest period before the flight about 16 hours

C Female, Aged 27: positioned in evacuation at door-R1

joined CPA Dec. 5, 1983
Latest training on emergency procedures Nov. 8, 1989
Total flight experience 3,421 hours 35 minutes (after Jan. 1,1985)
Rest period before the flight about 34 hours

D Female, Aged 30: positioned in evacuation at door-R2

joined CPA Jan. 7, 1985
Latest training on emergency procedures Feb. 6, 1990
Total flight experience 3,779 hours 37 minutes
Rest period before the flight about 70 hours

E Female, Aged 24: positioned in evacuation at door-L4

joined CPA Dec. 8, 1985
Latest training on emergency procedures Sept. 13, 1989
Total flight experience 3,144 hours 58 minutes
Rest period before the flight about 16 hours

F Female, Aged 25: positioned in evacuation at door-L1 assistant

joined CPA	Oct. 13, 1986
Latest training on emergency procedures	Dec. 8, 1989
Total flight experience	2,457 hours 27 minutes
Rest period before the flight	about 14 hours

G Female, Aged 23: positioned in evacuation at door-R1 assistant

joined CPA	Aug. 17, 1987
Latest training on emergency procedures	March 15, 1990
Total flight experience	1,752 hours 12 minutes
Rest period before the flight	about 34 hours

H Female, Aged 22: positioned in evacuation at door-R3

joined CPA	Feb. 22, 1988
Latest training on emergency procedures	Sep. 29, 1989
Total flight experience	1,434 hours 04 minutes
Rest period before the flight	about 82 hours

I Female, Aged 26: positioned in evacuation in front of the flight deck

joined CPA	April 11, 1988
Latest training on emergency procedures	Nov. 29, 1989
Total flight experience	1,249 hours 58 minutes
Rest period before the flight	about 44 hours

J Female, Aged 25: positioned in evacuationat Door-R3 assistant

joined CPA	April 25, 1988
Latest training on emergency procedures	Nov. 3, 1989
Total flight experience	1,233 hours 58 minutes
Rest period before the flight	about 137 hours

K Female, Aged 27: positioned in evacuation at Door-R4

joined CPA	June 27, 1988
Latest training on emergency procedures	Jan. 11, 1990
Total flight experience	1,126 hours 05 minutes
Rest period before the flight	about 36 hours

L Female, Aged 25: positioned in evacuation at Door-R4 assistant

joined CPA	June 27, 1988
Latest training on emergency procedures	Jan. 4, 1990
Total flight experience	1,100 hours 25 minutes
Rest period before the flight	about 15 hours

M Female, Aged 23: positioned in evacuation at Door-L3

joined CPA	Sep. 4, 1989
Latest training on emergency procedures	Sep. 29, 1989
Total flight experience	325 hours 45 minutes
Rest period before the flight	about 64 hours

N Female, Aged 24: positioned in evacuation at Door-L3 assistant

joined CPA	Jan. 8, 1990
Latest training on emergency procedures	Feb. 16, 1990
Total flight experience	46 hours 51 minutes
Rest period before the flight	about 18 hours

P Female, Aged 19: positioned in evacuation Door-L4 assistant

joined CPA	Jan. 8, 1990
Latest training on emergency procedures	Feb. 16, 1990
Total flight experience	45 hours 10 minutes
Rest period before the flight	about 18 hours

2.6 Aircraft Information

2.6.1 Aircraft

Type	Lockheed L1011-385-1
Serial Number	1042
Year of Manufacture	1973
Certificate of Airworthiness	No. 180 (issued by Hong Kong Government)
Validity	until July 17, 1990
Total Time	40,529 hours 17 minutes
Total Landings	20,574
Number of days after Inspection A(every 52 days) (conducted Feb. 28, 1990):	24 days
Number of days after Inspection C1(every 190 days or every 2,400 hours)(conducted Sept. 27, 1989) and flight hours:	178 days and 1,052 hours 43 minutes

2.6.2 Engines

The aircraft was equipped with three Rolls Royce RB211-22B engines.

Engine No.	Serial No.	Total Run Hours
1	10181	28,237 hours
2	10415	28,111 hours
3	10142	31,133 hours

2.6.3 Weight and Center of Gravity

The weight of the aircraft at the time of the accident is calculated as about 162,000 kilogram (about 357,000 pounds) and the center of gravity as 21.2% MAC, and both being within the allowable limits (the maximum landing weight is 166,922 kilograms (368,000 pounds); and the center of gravity corresponding to the weight at the time of the accident is 17.9 ~33.8% MAC).

2.6.4 Fuel and Lubrication Oil

The fuel on board was JET A-1 and lubrication oil was Aero Shell Turbine Oil 555, both being regular products for the aircraft use.

2.7 Meteorological Information

2.7.1 In Attached Fig. 6 is shown a part of Surface Chart (ASAS) at 0600 UTC of the day.

2.7.2 In Attached Fig. 7 are shown 850 hPa Chart (AUPQ85) at 0000 and 1200 UTC of the day.

2.7.3 Aeronautical Meteorological Observations at Narita Airport

The following are routine observations at the Aviation Weather Service Center, New Tokyo International Airport in the time zones relating to the accident. In addition, the special observation for the runway visual range (RVR) was conducted at 0503, 0512, and 0514 UTC. (wind direction in magnetic)

0428 UTC	Wind direction	230 deg(variable 210/270 deg)
	Wind speed	23 kt (variable, maximum 38 kt, minimum 9 kt)
	Visibility	4,200 meters SA
	Cloud	1/8 Cu 3,000ft 7/8 AC 12,000ft
	Tem/Dew Pt.	20°C/11°C
	QNH	29.63 inches Hg
	Remarks	Rising dust to all quadrants

0458 UTC	Wind direction	230 deg(variable 200/270 deg)
	Wind speed	22 kt (variable, maximum 38 kt, minimum 11 kt)
	Visibility	3,200 meters SA
	RWY visual range (RVR)	RWY 16 1,200 meters
		RWY mid-point 1,800 meters
		RWY 34 1,800 meters
	Cloud	1/8 Cu 3,000ft 3/8 AC 8,000ft 7/8 AC 12,000ft
	Tem/Dew Pt.	20°C/12°C
	QNH	29.62 inches Hg
	Remarks	PIREP: B747 (0448 UTC), loss in airspeed of 20 kt due to low level wind shear at 700 ft on final approach course to RWY 16. Rising dust to all quadrants

0528 UTC	Wind direction	230 deg(variable 200/270 deg)
	Wind speed	22 kt (variable, maximum 39 kt, minimum 10 kt)
	Visibility	3,200 meters SA
	Cloud	3/8 Cu 2,500ft 6/8 AC 12,000ft
	Tem/Dew Pt.	20°C/13°C
	QNH	29.60 inches Hg
	Remarks	Rising dust to all quadrants

2.7.4 The TAF-type Forecast issued at 2330 UTC of March 23 by the Aviation Weather Service Center, New Tokyo International Airport was as follows:

0000～2400 UTC : wind 220 deg/12 kt,
visibility 8,000 meters, haze, 2/8 Cu 2,000 ft
6/8 Sc 5,000 ft, 6/8 Ac 10,000 ft
with temporary changes:
0000～0200 UTC : visibility 3,000 meters
0300～0900 UTC : wind 230 deg/15 kt, maximum 27 kt,
visibility 4,000 meters, rain shower,
5/8 Cu 800 ft, 7/8 Sc 4,000 ft
1500～2400 UTC : wind 330 deg/17 kt, maximum 30 kt

2.7.5 In Attached Fig. 8 are shown the record of the propeler wind vane and anemometer (hereinafter referred to as the wind sensor) on the Runway 34 side, and record of temperature, dew point and atmospheric pressure at Narita Airport of the day.

2.7.6 In Attached Fig. 9 is shown the wind direction and speed, and temperature at 0500 UTC of the day in the Kanto Area, based on the observation by the Automated Meteorological Data Acquisition System (AMeDAS).

2.7.7 In Attached Fig. 10 is shown the "vertical profiles of temperature, dew point and wind at Tateno" for 0000 UTC and 0600 UTC of the day, made from observations at the Aerological Obsevatory (Tateno) of the Meteorological Agency .

2.7.8 In Attached Fig. 11 is shown a part of the record of wind direction and speed of the wind sensor on the Runway 16 side on the day in a time zone involving the time the accident occurred.
In Attached Fig. 12 is shown a part of the record of the wind direction and wind speed of 2 minutes mean on the Runway 16 side on the day in a time zone involving the time the accident occurred.

2.8 Communications

Before and after the landing, the aircraft maintained communication with the tower on Frequency 118.2 Mhz, but about the time it entered Taxiway Alpha Eight, the frequency was changed to 121.8 Mhz as instructed by the tower, and communication was established with the ground control. The communication was kept good on both frequencies.

2.9 Aids to Navigation and others

2.9.1 Airport

Runway 16 which the aircraft landed is 4,000 meters long and 60 meters wide. The elevation at the airport reference point is 134.5 ft, and the elevation of the touch-down zone of Runway 16 is 130 ft.

2.9.2 Aids to Navigation

On Runway 16 of Narita Airport are installed an ILS of the category II capability with the glide path angle of 3 degrees, reference datum of 59.1 ft, decision altitude of 280 ft and runway visual range of 500 meters, as well as a PAPI (Precision Approach Path Indicater) with the glide path angle of 3 degrees located 431 meters (1,414 ft) inside of the end of Runway 16.
April 2, 1990, a special flight inspection was carried out, using a CAB's flight inspection aircraft, on ILS (Localizer, Glideslope, Marker Beacon) of Runway 16 being operated with the transmitter which was in operation at the time of the accident as well as on PAPI and Approach Lights. The result of the inspection indicated that each facility was within their respective allowance limit as prescribed in the flight inspection standards and it was confirmed that they were in normal operation.
All aids to navigation and other facilities related to the flight route of the aircraft were in normal operation at that time.

2.10 Flight Data Recorder and Cockpit Voice Recorder

On board the aircraft was installed a Lockheed Aircraft Service Model 209 Digital Flight Data Recorder (hereinafter referred to as DFDR), and a Fairchild Model A100-30 Cockpit Voice Recorder (hereinafter referred to as CVR).
Both equipment, which were installed in the under-floor equipment compartment of the aft airframe, were recovered intact.
A part of the DFDR record was unreadable due probably to impact given at the landing . Furthermore, out of related parameters, the ILS glide slope deviation was recorded abnormally. Furthermore, it was found that the recorded values of the radio altimeter are different from the actual height above the ground level, since the altimeter was recorded without adequate adjustment done of the voltage divisive unit which was installed between its transceiver and DFDR.
Parameters of INS (Inertia Navigation System) data are not recorded in the aircraft.
CVR has four record tracks, and on each track, radio communication, voice, etc. were recorded in the following arrangement:

(1) Hot microphone of the captain and the copilot
(2) Audio selector panel on the copilot position
(3) Audio selector panel on the captain position
(4) Area microphone

Note:
The hot microphone is the microphone connected to the headset receiver. It is wired to CVR so that all input voice signals are recorded irrespective of selection on the audio selector panel.

2.11 Medical Information

Among a total of 301 persons on board consisting of a crew of 18 and 283 passengers, two passengers were seriously injured.
One of the seriously injured, according to the diagnosis of the hospital where he was accommodated, was subjected to "fracture-dislocation of the left ankle joint", while the other received the first aid treatment at the hospital. The diagnosis which he received at another hospital on a later date indicated "avulsion-fracture of the major tubercle of the right humerus". According to the statement of the two seriously injured passengers, they were injurerd, not while on board the plane, but during the emergency evacuation.
Besides, tens of passengers were slightly injured, and the injuries were bruise, sprain, graze, etc., according to the diagnosis of hospitals where they received a treatment.

2.12 Information on search, rescue and evacuation

2.12.1 Situation inside the aircraft at the hard landing

According to the statement of cabin attendants and several passengers, the situation within the aircraft at the time of landing was as follows:

The impact at the time the aircraft touched down was considerably intense, several oxygen masks fell, lids of many overhead stowedge opened, and some parts were damaged. Although some passengers shrieked momentarily, they were calm in general.

In the subsequent landing roll, air began to smell of fuel within the cabin. After the aircraft came to a stop, among passengers who observed fuel leaking on the ground, conversations were being exchanged between them such as "Fuel is flowing out".

2.12.2 Actions taken by crew in evacuation

(1) Emergency training of crew

The company regulations of the Cathay Pacific Airways prescribe training on emergemcy procedures to be conducted once a year to flight crew and cabin attendants, and record of the company indicated that the crew had received the said training as described in para. 2.5 " Crew Information".

(2) Actions taken by flight crew

After the aircraft came to a stop near the crossing of Taxiway Romeo and Taxiway Uniform, about 0515 UTC, the flight crew received from the ground control messages "Looks like oil leaking" and "Stop your engines", and subsequently monitored an aircraft located near parking spot 406 transmitting to the ground control "Considerable smoke coming from the left-side landing gear of the Cathay Tristar...[unreadable].. .... unaware of it ...."

The copilot, as directed by the captain who had thereby recognized the possibility of fuel leak, reported about 0515:30 UTC to the ground control "Request fire services coming up to the aircraft on stand by ...". The chief purser was also called in the cockpit, and was instructed to provide for a possible emergency evacuation. Thereafter the captain, who observed the spillage of considerable fuel around the aircraft through the left window, repeated about 0516:30 UTC the request of fire services "We got a fuel spillage. We need the fire trucks in attendance straight away please". (This request was almost unreadable to the ground control controller due to interference with transmission from other traffic.) The captain decided to make an emergency evacuation, and ,after stopping engines, instructed them orally by the passenger address system "Evacuate. Right side only" repeating it three times.

Note: There is the following description in para. 5.3. "Distress and urgency radiotelephony communication procedures" of Volume II of ICAO Annex 10 "Aeronautical Telecommunications":

"The radiotelephony distress signal MAYDAY and the Radiotelephony urgency Signal PAN PAN shall be used at the commencement of the first distress and urgency communication, respectively"

(3) Actions taken by cabin attendants

Cabin attendants were seated as established at the time of landing. Since air smelled of fuel within the cabin during landing roll, the chief purser went to the cockpit and reported to that effect. Soon after the aircraft came to a stop, the direction of emergency evacuation was issued by the captain, and the emergency lights within the cabin came lit. The chief purser and the cabin attendants in charge announced in English, Kantong Dialogue and Japanese that an emergency evacuation was to be effected, and requested at the same time passengers, not to bring out baggage with them, to take off high-heels, and to remove glasses as matters of caution with the evacuation.

Other cabin attendants were posted respectively in accordance with the emergency procedures of the aircraft, and after the full stop of the aircraft and the safety outside of the aircraft were confirmed, opened each door of the right side R1, R2, R3 and R4 as directed by the captain; while the chief purser opened L1 door and deployed the escape slide. Cabin attendants, who descended to the ground through R1 and R2 of which the escape slide was usable, held down the slides flapping up due to the strong wind and provided passengers with evacuation assistance and guiding services. Remaining cabin attendants engaged in guidance of passengers at their respective discretion.

2.12.3 Evacuation from each door

According to statements taken from all cabin attendants, the emergency evacuation was conducted from each door as follows:

(1) R1 door

Cabin Attendant C opened the door, and after the escape slide was deployed, guided the evacuation of passengers standing beside the door. Cabin Attendants F and G descended to the ground and helped passengers to escape.

Thereafter a part of passengers, the flight engineer who had deplaned, and maintainance personnel who rushed to the site, participated in the supporting work, but soon the escape slide being flapped by strong wind. The number of persons who evacuated from R1 door is not clear, but estimated to be about 100.

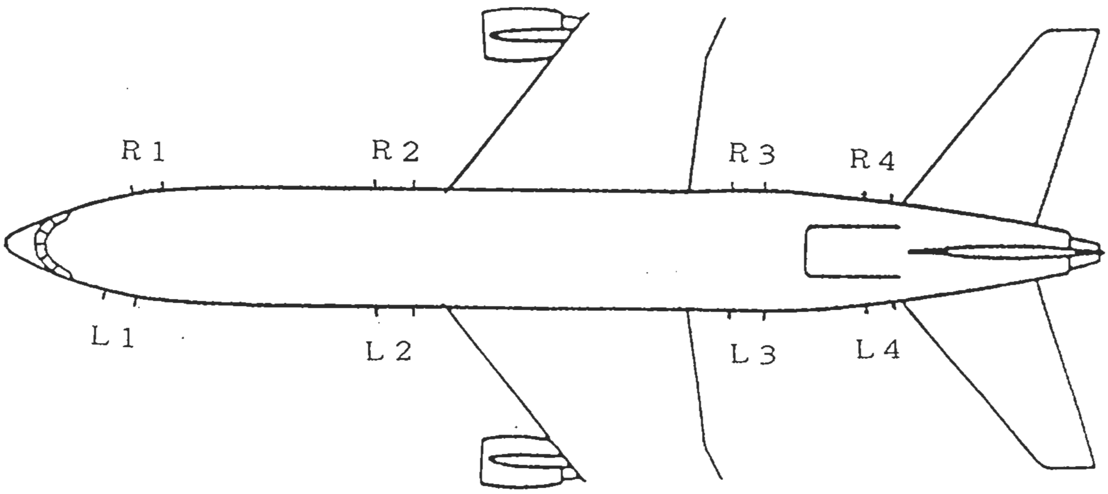
(2) R2 door

Cabin Attendant D opened the door, and after the escape slide was deployed, Cabin Attendant J descended to the ground, held the escape slide and helped passengers to escape. Thereafter Cabin Attendant I, passengers, and maintainance men who rushed to the site supported on the ground the evacuation of passenger. All passengers, except for those who escaped from R1, evacuated from R2 door.

(3) R3 door
Cabin Attendants H and M opened the door. The escape slide, as soon as it was deployed, became unusable because it was flapped by a strong wind from the right aft, twisted and floated above the ground. Then, H blocked the door by standing in front of R3 door, and guided passengers to R2 door, while M guided passengers in the aft cabin fore to R2 door.

(4) R4 door
Cabin Attendants K and L opened the door. The escape slide, as soon as it was deployed, became unusable because it was floated up by a strong wind from the right aft. K blocked the door by standing in front of R4 door, and guided passengers fore, while L guided passengers in the aft cabin fore towards R2 door.

(5) L1 door
The chief purser, who heard the captain's instruction "Emergency evacuation from the right side" only as "Emergency evacuation", opened immediately L1 door. The escape slide, however, was unusable being flapped by wind. Then she hooked the door with the safety strap, and guided passengers to R1 door.



Location of Emergency Doors

2.12.4 Reaction of passengers at the time of evacuation

According to statements of part of passengers, cabin attendants, and the fire fighting personnel, the situation in which the emergency evacuation and refuge were taken was as follows:

The passengers were generally composed during the emergency evacuation and escaped orderly in accordance with instructions of cabin attendants. Among passengers there were persons who escaped carrying personal effects with them irrespective of the caution previously given. There was no person at all who scrambled for the exit, but some of passengers aft in the row were found somewhat irritated, since Doors R3 and R4 located aft were unusable. Although the escape slide was held down on the ground by the personnel, some of passengers could not land smoothly because the slide was made unstable due to the intense wind. Furthermore, some passengers tumbled down, because fuel spilled on the taxiway around the aircraft making the surface slippery. Most of passengers who evacuated took refuge in a lawn area or on the taxiway more than 100 meters distant east or north, and leeward, of the aircraft.

2.12.5 Fire fighting and rescue service at Narita Airport

(1) Outline of the fire fighting and rescue service at Narita Airport
The fire fighting and rescue service is a service to be provided by the Airport Authority, and the Airport Authority has concluded agreements on fire fighting and rescue activities with Chiba Prefecture, neighboring local communities, and related medical associations for their assistance made available any time upon request.

The fire fighting and rescue is maintained in shifts on a 24-hours service basis. The fire fighting and rescue system meets the requirements prescribed in ICAO Annex 14 "Aerodrome" with respect to equipment, personnel, etc. On the day of the accident 22 fire fighting personnel were on duty.

(2) Notification of information and request of services
Notification about occurrence of aircraft accident and request of the services are made to the Control Room of the Fire Station of the Airport Authority from the Tower or the Flight Operation of the New Tokyo Airport Office of the Ministry of Transport, the Operations Office of the Airport Authority, airlines office, etc. The Control Room, upon reception of the notification or request, broadcasts, using a microphone capable of simultaneous broadcasting, directions to the fire station and its satellite. Furthermore, the Control Room could request, when necessary, assistance of the Fire Fighting Headquaters of Narita City and other related units. Meanwhile, the fire station is also always on the watch by posting a watcher.

2.12.6 Recognition of the abnormal situation, request and dispatch of fire fighting rescue services, and the fire fighting and rescue activities

(1) Recognition of the abnormal situation
The Fire Station of the Airport Authority, by the request of the tower, was carrying out the "Stand-by of the Crash Crew" by posting two fire

trucks on shifts in front of its satellite.

Note: "Stand-by of the Crash Crew" would be conducted, in accordance with an arrangement between the Airport Authority and the New Tokyo Airport Office of the CAB, when the crosswind component of the runway is more than 20 kt or the ground visibility is less than 1,200 meters, in which case the personnel stand by on board the fire vehicles in front of the Fire Station with the engine kept run.

After the aircraft entered Taxiway Alpha Eight, the tower controller observed an oil-like "stripe" glimmering black and trailing after the aircraft, and the ground control and the senior controller engaged in supervising positions of the tower were informed of the fact.

The ground control, taking into account the possibility that should it be a fuel leak, and when the taxing aircraft entered the parking spot and took fire, the fire hazard would involve other aircraft and substances in the spot, and on a reason that the aircraft looked like proceeding a taxiway different from instructed, requested the aircraft to stop and advised "Looks like oil leaking" and to stop engines. The aircraft came to a stop about 0514:30 UTC near the crossing of Taxiway Romeo and Taxiway Uniform.

About 0515:30 UTC, the aircraft transmitted to the ground control "Request fire services coming up to the aircraft on stand by" and "We would like a tug, as well, to tow us in", but the transmission was unreadable to the controller, at which time the controller could not request the aircraft to make a re-transmission, since another controller asked his coordination on taxiway assignment for a subsequent landing aircraft and a communication with a taxing out aircraft was cut in.

About 0516:30 UTC, during the time when another aircraft reporting the situation of considerable smoke coming from the aircraft, the captain again requested "We got a fuel spillage . We need the fire trucks in attendance straight away please", but this massage was again unreadable to the controller due to intereference by a transmission of other aircraft.

The ground control controller, cognizant of a situation abnormal in a way or another the aircraft was in, asked assistance of the senior controller in charge of supervising positions of the tower at that time.

(2) Emergency procedures and request of fire fighting and rescue services

The senior controller, who observed immediately thereafter the aircraft had commenced an emergency evacuation, decided to take emergency procedures, and notified closure of the runway to all units concerned involving the Central Operation Room of the Airport Authority, and at the same time about 0518:30 UTC notified the Control Room of the Fire Station on the hot line that the aircraft came to a stop on the taxiway with a possible fuel leak and began an emergency evacuation, and asked them to dispatch a fire fighting team. The senior controller observed about one minute thereafter matters shinning black spreading out on the taxiway surface near the aircraft, and judged the leakage as considerable, and repeated the request through the crash phone.

Note: The crash phone a exclussive circuit capable of simultaneous talk from the tower's supervisory position to the Control Room of the Fire Station of the Airport Authority and the Central Operation Room of the Airport Authority, and the Flight Operation Room of the New Tokyo Airport Office, for exclusive use in emergencies such as aircraft accident.

(3) Dispatch of fire fighting and rescue vehicles

About 0519 UTC, upon receipt of the first request from the tower, the Control Room issued a Class 1 Order (the alert order) to the fire station and its satellite; and one commanding car, one fire fighting truck and 2 water tank trucks departed for the site. In addition, about 0520 UTC, upon receipt of the second request from the tower, the Control Room issued Class 2 Order (the emergency order), whereby one fire fighting truck, two ambulances, two water tank trucks and one crash rescue truck were sent from the Fire Station and its satellite. Furthermore, by the direction of the commander on duty, a fire fighting truck, which was moving on another mission, aborted the schedule to join the operation.

Note: "Class 1 Order" is the order to prepare the fire fighting and rescue vehicles for immediate departure to the site.

"Class 2 Order" is the order to prepare the fire fighting and rescue vehicles for departure to the site and immediate fire fighting and rescue services.

(4) Fire preventive measures at the site

Judging synthetically from records of the fire station, and statements of fire fighting personnel and ground maintenance men who rushed to the site, it was about 0523 UTC that the fire vehicles arrived at the site, at which time most of passengers had escaped and took sheltered, but evacuation was still going on through R2 door. Upon arrival one of the fire fighting truck discharged the foam extinguisher for about 15 seconds (about 1,300 liters) against leaked fuel below the fuselage as a fire preventive measure. Fire fighting vehicles of the fire station of Narita City arrived at the site about 0532 UTC.

(5) Shelter for passengers and first-aid services

Since passengers took shelter on the leeward of the aircraft, the fire-fighting commander pursuaded them to move windward because it would be hazardous, should fire had occurred, although the shelter was distant more than 100 meters from the aircraft. Nevertheless, most passengers did not move. Rescue men began the first aid services to the injuried. Seven injured persons accommodated into the ambulances, according to record of the Fire Station, departed the site 0540 UTC and arrived at a hospital in Narita City for the first aid treatment. The rest of passengers left the site on limousines. The injured pasengers received the first aid at a medical clinic within the airport, and about 30 passengers who so desired were given thereafter separately the first aid treatment at the said hospital.

2.12.7 Injuries

Two passengers were seriously injured by bone fracture, and tens of passengers and cabin attendants were slightly injured by abrasion, tortion, etc. One of the seriously injured passengers stated that when he came down on the ground through R2 escape slide, he could not stand up, and therefore he thought he was injured at that time; while the other stated that R2 escape slide swayed in the wind and his body was struck heavily when he landed on the ground, at which time he would have been injured. As to other slightly injured passengers, according to Cathay Pacific Airways, they were told that their injuries were made at the time of emergency evacuation.

2.13 Other necessary information

2.13.1 A Warning Description for Narita Airport in the Route Manual

The "Route Manual" of the Cathay Pacific Airways distributed to flight crews has the following description as a warning for Narita Airport, of which the captain and the copilot are said to have been cognizant:

"Windshear : Under certain conditions notably a strong westerly/south-westerly airflow, low level windshear may be anticipated. This is a significant hazard"

2.13.2 Crosswind Limitation

According to the L-1011 Operations Manual of the company, the crosswind limit at landing is 35 kt (the crosswind component including gust) in case where the runway is non-contaminated.

2.13.3 Approach Speed

When approaching in gusty conditions, an increase in approach speed is required to cater for rapid airspeed changes. Taking this factor into cosideration, the L-1011 Operations Manual of the company prescribes that increments to the landing reference speed (VREF) should be as follows:

(1) During initial approach, 1/2 wind + gust factor (maximum 20 kts

increase)

(2) As height decreases, the 1/2 wind factor should be reducing, so that at threshold point, speed above VREF is the gust factor only (maximum 15 kts increase)

(Note) the gust factor = the maximum wind minus the average wind

2.13.4 Standard of the escape slide against wind

At the time of type certification of the aircraft, the escape slides must be proved to meet the design and test standards which prescribe that they be deployable normally in the wind of 25 miles per hour (21.7 kt).

3 Analysis

3.1 Tests and Research for Analysis

3.1.1 Error Correction of DFDR Records

The DFDR is a flight data recorder adopting the digital recording sysyem, in which data transformed into a line of two kinds of signal "0" and "1" are recorded in series.
The signal is composed of 12 bits = 1 word, and is recorded at 64 words per second. In the foremost word slot of each second is recorded the synchronous signal, and in the remaining the 2nd to the 64th word slots various parameters are recorded in an established order and cycle, and recording of all parameters is made in a cycle of 4 seconds.
The DFDR decoder performs its work confirming every second that the synchronous signal exists in the established place, and if the synchronization failed, an error mark would appear which indicates there is an error involved in the results decoded within one second thereafter.
As a result of decoding of DFDR record of the accident aircraft, error marks were found in succession for 3 seconds near the moment the aircraft would have touched down. A more detailed study of the data indicated that an amount of bits were lost due to the shock at the time of touch-down. A trial to recover the data was made by shifting fore and hind bits in a line, whereby most of the data were repaired within 3 seconds where error marks appeared except for about 10 words after the moment of touch-down.

The parameter of the radio altitude was corrected using a corrective coefficient obtained separately, because, as stated in para. 2.10, insufficient adjustment was found of the voltage divisive unit incorporated between the transceiver of the radio altimeter and the DFDR.

3.1.2 Meteorological analysis

Since no wind data had been recorded on DFDR of the aircraft, the following analysis was made to estimate winds the aircraft encountered during the period from the final approach to landing.

3.1.2.1 Synoptic weather situation at the time of accident

At 0600 UTC of the 24th day, near the time the accident occurred (0512 UTC:1412 JST), a Low of 1000 hPa was located on the ocean east of the Honshuu, from where a cold front was extending as far to the Kyuushuu Island passing through a northern part of the Kanto Area. (see Attached Fig. 6) The cold front passed Narita Airport about 1140 UTC of the 24th day, until which the wind had been from SSW～SW with a significant intensity for the period of 0030 UTC to about 0830 UTC. (see Attached Fig. 8) In front of the cold front is recognized a strong wind belt extending from the Izu Peninsula and reaching near Narita Airport through Tokyo Bay, in accordance with data of the Automated Meteorological Data Acquisition System at 0500 UTC, the nearest to the time of accident. (see Attached Fig. 9)

Since, as shown in Attached Fig. 9, Narita Airport was in the same area of strong wind as the Aerological Observatory at Tateno in Tukuba City (located approximately 40 km NW of Narita Airport), the data of upper air currents observed at the observatory were used to estimate its vertical structure at Narita Airport. (see Attached Fig. 10) According to this, there was an inversion layer at height of 960～900 hPa at 0000 UTC with the maximum wind speed of 15.9 m/s (31 kt) from 218° at 944 hPa (a height of 580 meters).

It is conceivable that there existed, also at the time of accident, an inversion layer or a stable layer at a low altitude, judging from fact that the maximum wind speed was 13.5 m/s (26 kt) at an altitude of 978 hPa and that the wind speed profile was similar to that at 0000 UTC, although the temperature curve is unknown because temperatures were not included in the aerological observation at 0600 UTC the nearest to the time the accident occurred.

According to an analysis (see Note below) made by the Aviation Weather Service Center of Narita Airport concerning 757 pilot reports of the wind shear and turbulence for a period of six years from 1984 to 1989, significant meteorological conditions common to the reports in case the wind was from SW were: in most cases, (1) the maximum wind exists below 900 hPa, (2) a stable layer or an inversion layer exists, (3) a diurnal change can be seen in the surface wind from SW, and a strong wind from SW appears for the period of 0000～0700 UTC, most frequently at 0500 UTC. The meteorological conditions at the time this accident occurred would meet those above.

(Note)

* Forecast Division of Japan Meteorological Agency, Tokyo Aviation Weather Service Center and New Tokyo Aviation Weather Service Center (1988): Forecast methods of wind patterns affecting the take-off and landing of airplanes (Report 1)
Journal of Meteorological Research Vol 40 (1989) 143-168

* The same as above (Report 2) ibid Vol 41 (1990) 215-240

* The same as above (Report 3) ibid Vol 42 (1990) 69-87

3.1.2.2 Distinguished features of the surface wind at the time of accident at Narita Airport

(1) Narita Airport was in a strong wind belt (lower level jet).

(2) The wind speed at Runway 16 is smaller than at Runway 34 in the average, but it is larger in the gust. The ratio of the instantaneous maximum wind speed to 10 minute average wind speed is larger for Runway 16 than for Runway 34, but the average wind speed is larger for Runway 34 than for Runway 16. This is characteristic of Narita Airport when it is subjected to a strong wind from South West. (see Attached Table 1)

(3) It is noted that the accident occurred in the time zone where the turblence was significant, in view of the fact that, according to the 2-minute wind sensor (see Attached Fig. 12), remarkable changes in wind direction were during a period of 0430 UTC to 0600 UTC, and the maximum wind speeds were high during a period of 0500 UTC to about 0540 UTC. The right side of the red line in Attached Fig. 12 is a tailwind portion, as the tail wind frequently appeared as an instantaneous value on the day of the accident.

(4) In records of the wind direction and the wind speed, there are variations in the wind speed and direction having a period longer than the gust, ranging from several minutes to slightly more than 10 minutes. (see Attached Fig. 11)

3.1.2.3 The wind the aircraft encountered at the time of approach and landing as estimated from records of Runway 16 wind sensor and records of other aircraft

Since data on the wind are not recorded, as stated above, in DFDR of the aircraft, the wind the aircraft enountered at the time of approach and landing was estimated from the data of the wind direction and speed recorded on an aircraft (referred hereinafter to as Aircraft 'A') which landed 27 minutes before the accident aircraft, and another aircraft (hereinafter referred to as Aircraft 'B') which landed 6 minutes after the accident aircraft as well as records of the Runway 16 wind sensor.

The details are shown in Addendum 1.
(1) The wind the aircraft (VR-HOC) encountered during approach and landing is estimated as "between Aircraft 'A' and Aircraft 'B' in the wind direction, and at a similar level with Aircraft 'B' in the wind speed."

(2) The wind the aircraft 'A' and 'B' encountered on their approach varied in its direction and speed with the height. The variation in the wind speed would have been a horizontal variation due to the topography, for a reason that if the variation in the wind speed had been caused by a vertical wind shear, its scale must have been 34 ~ 38 meters/second per 100 meters for aircraft 'A', and a vertical wind shear of such an extent should be unconceivable. (see Attached Fig. 13)

(3) Change in CAS (Computed Air Speed) and wind during approach and landing

a. Abrupt decrease in CAS at about 1.6 km short of the approach end of Runway (see para. 3.1 of Addendum 1)

The CAS of the aircraft suddenly increased to a maximum of 172.6 kt near about 1.9 km short of the approach end of runway. This location is near the place where the flight course crosses a valley (Valley U2 in Attached Fig. 13) running at a bearing of about 200 degrees. Since the prevailing wind around there is 225 deg/35 kt for Aircraft 'A', and 210 deg/45 kt for Aircraft 'B', the headwind component to the direction of the approach course is 9 kt for Aircraft 'A', and 22 kt for Aircraft 'B'.

After passing this valley, CAS of the aircraft abruptly decreased 25 kt in 5 seconds. This sector is located on the leeward side of a hill about 40 meters above sea level, and the abrupt change in CAS is considered to have been caused by the topography. From the wind data of Aircraft 'A' and 'B' it is also conceivable that the wind changed northward in this vicinity. According to the CVR record of the aircraft, the warning sound of the "glide slope" of GPWS was acctivated around this time.

b. Abrupt change in CAS in the vicinity of the middle marker (see para. 3.2, Addendum 1)

CAS of the aircraft as well as Aircraft 'A' and Aircraft 'B', all reached their maximum over a plateau near the middle marker. The CAS was also greatly variable immediately before that time.

The area where variation in CAS was intense is of such complicated topography that from 200 meters ahead on the upstream side is lying the outside of the airport where sunken places and hills are abound and a valley (Valley U1 in Attached Fig. 13) running on a bearing of about 200 degrees is crossing. The plateau on which the middle marker is located is also of such a topography that the wind blows up along a steep slope.

c. Abrupt decrease in CAS immediately before landing
(see para. 3.3, Addendum 1)

After passing the middle marker, CAS of the aircraft abruptly decreased from near the mid point between the marker and the inner marker. Such a trend is also can be seen for Aircraft 'A' and Aircraft 'B'. In case of Aircraft 'A' and Aircraft 'B', the wind decreases abruptly from the vicinity of the inner marker.

Since such an abrupt decrease in the wind speed is unconceivable as a vertical wind shear, the topography would be attributable to it. A check of the cross section in the direction of the average wind of the topography in this sector indicates that the portion where the wind is strong is, as stated above, of such topography that the wind blows up along a steep slope on the windward side, while the portion where the wind is weak is a wide and flat area within the airport.

After passing the inner marker, near the runway end at a height of about 40 ft, CAS of the aircraft became temporarily 146 kt, decreasing 12 kt for a second. but there are no such abrupt decrease for Aircraft 'A' and Aircraft 'B'.

The runway 16 wind sensor recorded a wind direction of 310 deg and a wind speed of 35 kt as a maximum at a recorded time of about 0511 UTC, but it is unknown that the maximums of the wind direction and the wind speed coincide chronologically with each other.

For this portion, however, a wind direction of 287 deg (red arrow mark in Attached Fig. 12) and a wind speed of 27 kt are recorded in the 2-minute wind sensor as 3-second average values, and when movement of an eddy is taken into account, a chronological consistence could exist. From this, it is conjecturable that the aircraft would have temporarily been subjected to a tailwind although its absolute value is unknown.

It is not clear how the topography on the windward side of the location where the wind sensor is installed is related to the occurrence of the eddy.

(4) Existence of local downdraft

Although a possibility is conceivable that an extremely local downdraft due to eddies might have some influence on increase in the descent rate immediately before the aircraft touched down, its existence was not clarified because of lack of observation of the vertical currents.

(see Note below)

Note: H. Nirasawa, H. Ohno, O. Suzuki (1991):
A Fine Structure of the Gust Front Observed with Sonic Anemometer
4th International Conference on Aviation Weather Systems
(Preprints P278-280)
American Meteorological Society

3.1.3 Estimation of descent rate, wind and descent profile

3.1.3.1 Estimation of descent rate

Based on readouts of DFDR on the radio altimeter altitude and the vertical acceleration, and using the Karman Filter, the descent rate was estimated for a period from a height above the touch-down zone's elevation mark (hereinafter referred to as "height") of 400 meters down to the touch-down. The Karman Filter is a method to estimate a status amount at a certain time in a manner the most probably accurate, when the status equation (motion equation) representing the system's characteristics as well as the error distribution involved in each estimation are known.
Results of the estimation on descent rates are shown in Attached Fig. 14b. It is estimated that the descent rate of the aircraft abruptly increased immediately before touch-down, reaching as much as 21 ft/second.

Details of the estimating processes are shown in Addendum 2.

3.1.3.2 Estimation of wind from Motion of Aircraft

The wind the aircraft encountered was estimated by the following processes. However, only the wind within the horizontal surface was considered assuming that the wind in the vertical direction was negligible because the altitude was low.

Details of each process are described in Addendum 2.

(1) Estimation of wind speed in the heading
By the process below, the wind speed in the heading was estimated.

1) obtain the acceleration to the longitudinal direction of the aircraft, from the forward acceleration and the pitch attitude angle in DFDR, and, by integrating it and carrying out a coordinate conversion, calculate the ground speed to the runway direction.
2) determine the integral constant used in calculation of the ground speed by estimating the average ground speed between the middle marker and the inner marker from the time needed for the passage of the sector.
3) obtain the wind speed in the heading from the difference between the ground speed so acquired and the airspeed (in DFDR).

(2) Estimation of crosswind

By the process below, the crosswind was estimated.
It is impossible to estimate the crosswise wind by the same method as used in the calculation of the longitudinal wind in (1) above, since no side-slip angle of the aircraft is recorded in DFDR and the recorded data on the lateral position is also less accurate. Therefore, using the Karman Filter in the same manner as in the estimation of the descent rate in para. 3.1.3.1, an estimation was made of the crosswind to the aircraft axis by reconstituting measurements concerning the motion of the aircraft to the lateral direction (each operated amount of aileron, spoiler and rudder, roll and yaw attitude angles, and lateral acceleration). The aircraft characteristics used in the calculation are based on data provided by the Lockheed Company. Results of the estimation are shown in Attached Fig. 14c.

(3) Estimation of wind direction and speed

From results in (1) and (2) above was obtained the wind direction and speed the aircraft encountered in the coordinate system fixed on the ground. Results of the estimation are shown in Attached Fig. 14d., in which the wind direction is measured clockwise from the runway direction. Furthermore, its comparisons with the winds which Aircraft 'A' and Aircraft 'B' encountered are shown in Attached Figs 15, 16 and 17.
The estimation results above would approximate the results of analysis in para. 3.1.3.2 stating that "The wind the aircraft (VR-HOC) encountered is estimated to have been between Aircraft 'A' and Aircraft 'B' in wind direction, and at a similar level with Aircraft 'B' in wind speed", and would therefore be considered greatly reliable.
According to the estimation, the wind the aircraft encountered was:

(a) The wind speed was less than 20 kt at a height of about 200 ft.
(b) At heights of 100 to 50 ft, the wind speed reached about 40 kt with a direction almost crosswise at right angles to the aircraft.
(c) From a height of about 50 ft, the wind speed abruptly decreased and the direction also considerably changed, and at a height of about 40 ft, the wind turned temporarily to a tailwind. The longitudinal component of the wind changed about 12 kt in about one second from the height of 50 to 40 ft.

3.1.3.3 Estimation of descent profile

The descent profile of the aircraft was estimated, on the basis of the relationship between the height of the aircraft and the time which had been obtained in the estimation of the descent rate in para. 3.1.3.1, and the relationship between the ground speed and the time which had been obtained in the estimation of the wind in para. 3.1.3.2, as well as the passing time over the inner marker.

Results of the estimation are shown in Attached Fig. 18. The initial touch-down point of the aircraft is also estimated to have been about 230 meters inside of the approach end of runway.

3.1.4 Investigation on fracture surfaces of damaged portion around the rear spar of the root of the left wing.

A visual macroscopic analysis as well as a microscopic analysis by the replica method using an electron microscope were conducted on fracture surfaces of the damaged portion near the rear spar of the root of the left wing as described in para. 2.3.2.2.
Prior to the analysis of fracture surfaces, a visual observation was carried out after exposing the cracked surfaces by cutting the rear spar web near IWS 300 from the upper end to the damaged portion, also by cutting, as necessary, the wing-and-fuselage connecting fitting where cracks were found.
Locations where replicas were taken are indicated by mark together with identification symbols in Attached Fig. 5.

(1) Fractured surfaces near IWS 241

As to the rear spar web, the fracture surfaces would have been formed along rivet holes by a static failure due to shear and tension load. Surfaces with a dimple pattern, peculiar to the static failure, were prevailing, except for a fracture surface having a fan-like pattern caused by fatigue about 2 mm in diameter on the edge of a rivet hole. It was recognized that this fatigue failure surface was not the origin from which the static failure started.
The stiffener at the same location was damaged at the portion where it is attached to the upper spar cap located at its upper left, but it was recognized that the fracture surface was caused by a static failure due to shear and tension load.
It was also observed that the fracture surface of the upper spar cap was formed in the same manner.

(2) Fracture surfaces near IWS 300

In the vicinity of IWS 300, the rear spar web was fractured by buckling in such a manner as to be projected rearward and deformed. On each forked cracked surface was found the dimple pattern. All these surfaces would have been formed by a static failure due to shear and tension load.
The similar dimple pattern was observed on cracked surfaces caused on the upper spar cap and the lower spar cap in the vicinity of the station, and it was recognized that they were also caused by a static failure.

(3) Fracture surfaces of the fitting connecting wings and fuselage

The upper forward inboard and the upper outboard fitting were cracked at

their respective locations where connecting bolts are fixed.
Dimply-patterned surfaces are prevailing among cracked surfaces on the upper forward inboard fitting in the same manner as other fracture surfaces, and it was recognized that they were caused by a static failure and with a loading at one time.
As to the upper outboard fitting, a part of its failure surfaces were unanalyzable because of cutting and boring process which would have been done when it was dismantled from the airframe. An analysis made on available fracture surfaces indicated that they were caused by static load in the same manner as other damaged portions, except that a striation was observed indicative of growth of a fatigue crack on a slight portion of the tip of a crack caused by a static failure. It was recognized that the fatigue crack was formed in succession to the static failure.
This analysis could not specify the time at which the fracture surfaces were caused on the upper forward inboard fitting and the upper outboard fitting, but it was recognized that none of the fracture surfaces constituted the original point from which the damage to the rear spar of the left wing started in this accident.
None of remarkable corrosion, deterioration, or other defects were recognized on the materials in the vicinity of the damaged portion.

3.1.5 Transmission Speed at the time the fire service was requested

In reference to the fact that the initial request on fire services from the flight crew was unreadable to the controller, its transmission speed was examined using a voice analyzer on the basis of CVR records.
The time required for the flight crew to transmit the massage "Request the fire services coming up to the aircraft on stand by" was about 2.7 second, and the transmission speed was about 150 words/minute.
The request of fire services sent secondly from the flight crew was unreadable to the controller due to interference with another transmission. The investigation was made for a reference purpose on the time which would have been required to transmit "We got a fuel spillage. We need the fire trucks in attendance straight away please". The result was that the time needed was about 3.0 seconds, and the trasmission speed about 200 words/minute.
Note: In para. 5.2.1.4 "Transmitting Technique" of Volume II of ICAO Annex 10 "Aeronautical Telecommunications" is described a provision that "Aircrew and ground personnel should maintain an even rate of speech not exceeding 100 words per minute (para. 5.2.1.4.3.b)"

Furthermore, the following is described in para. 9.1.5 of ICAO Doc 9432-AN/925 "Manual of Radiotelephony" :

"Pilots making distress or urgency calls should attempt to speak slowly and clearly"

3.2 Analysis

3.2.1 The flight crew was properly and qualified, and had passed the medical examination.

3.2.2 VR-HOC had a valid airworthiness certificate, and had been maintained and inspected as prescribed.

3.2.3 ILS, PAPI, and approach lights were in normal operation at the time of landing of this aircraft.

3.2.4 Meteorological situation at the time of approach and landing

3.2.4.1 It is recognized that Narita Airport was, at the time the accident occurred, in a warm area in front of a cold front extending from a Low Pressure off the Sanriku Coast, and was in a strong wind belt from SW originating at Izu Peninsula and reaching around Narita Airport through Tokyo Bay.

3.2.4.2 According to records of the 2-minute wind sensor, it was about from 0430 to 0600 UTC that the variation in wind direction on the Runway 16 side was remarkable, and about from 0500 to 0540 UTC that the maximum in wind speed was large; and the accident occurred in this time zone in which the gustiness was significant. (see Attached Fig. 11)

3.2.4.3 From results of the test and research in paras. 3.1.2.3 and 3.1.3.2, it is estimated that the wind direction and speed while the aircraft was approaching to land varied considerably with the position of the aircraft. The variations in wind direction and speed would be attributable mainly to effects of the topography below the flight course as well as on the windward side of the course.

3.2.4.4 In view of meteorological conditions at that time, it is considered that no such meteorological phenomena existed as a downburst caused by convective clouds on the final approach course to Runway 16.

3.2.5 Approach and Landing
In Attached Fig. 19 is shown the chronological sequence up to touch-down of the aircraft from the height of 400 ft, while in Attached Figs. 20 and 21 are shown details of the longitudinal and the lateral motion from 6 seconds prior to touch-down. In these figures, the height, rate of descent, ground speed, and wind direction and speed are values which were estimated in para. 3.1.4, and others are readouts of DSDR.

3.2.5.1 Crosswind Component
The crosswind component calculated from the wind direction and speed which were given from the tower to the aircraft on approach is within 35 kt, the crosswind limit set forth in Cathay's L-1011 Operation Manual.

3.2.5.2 Target Approach Speed

The captain set,in accordance with the operation manual, the target approach speed at 162 kt, i.e., 142 kt, the landing reference speed (VREF) corresponding to a landing weight of 360,000 lb with a flap of 33 degrees, plus 20 kt, a correction for the wind. His setting of this target approach speed was pertinent, judging from the meteorological information given from the tower.

3.2.5.3 Wind at distance of about 1.9 km to Runway End

CAS of the aircraft increased up to 172.6 kt at a height of about 350 ft and a distance to the runway end (hereinafter referred to simply as "distance") of about 1.9 km. This location was near the place where a valley running on a bearing of about 200 degrees crossed the flight course, and where the headwind is estimated to have been comparatively strong.

3.2.5.4 Wind at distance of about 1.5 km

Five seconds thereafter, CAS of the aircraft abruptly decreased to 148 kt, far below the target approach speed; and the descent rate also temporarily reached as much as 20 ft/second. For this reason, the height of the aircraft became lower more than 0.7 degree than the glide slope around a distance of 1.5 km. This place where the CAS abruptly decreased is located on the leeward side of a hill 130 ft above sea level, where the aircraft is considered to have encountered a tailwind or a crosswind at a right angle judging from the results of analysis in paras. 3.1.3.3 and 3.1.4.2.

According to records of CVR, 23 seconds before touch-down, the soft sound (mode 5) of the "glide slope" of the GPWS became activated. The reason therefor is estimated to have been that the height of the aircraft became lower more than 1.3 dots (0.47 degree) than the glide slope.

3.2.5.5 Wind in the vicinity of Middle Marker

CAS of the aircraft was recovered by change of the wind and increased engine thrust, and, at a height of about 160 ft and a distance of about 0.8 km (near the middle marker), became 160～170 kt, although being subjected to abrupt changes ranging 5～10 kt.
Around this time, to cope with the crosswind, the aircraft took a crab angle of about 5 degrees to the right. According to the estimation of the wind in para. 3.1.3.2, the wind which the aircraft encountered hereabout came down to less than 20 kt.
The abrupt change in CAS in the vicinity of the middle marker is more remarkable for Aircraft 'A' and Aircraft 'B'. It is estimated that this would have been caused by a wind variation due to effects of the complicated topography involving caves and hills located on the upstream side.

3.2.5.6 Wind and Control Operation from 120 ft to 50 ft in height

At a height of about 120 ft and a distance of about 0.6 km, the crab angle

was increased to the right, a wing low being applied in parallel, and a roll attitude angle of about 5 degrees was taken to the right. The crab angle to the right reached a maximum of 14 degrees at a height of about 70 ft.
According to the estimation of the wind in para. 3.1.3.2, the wind, which came down to less than 20 kt at a height of 200 ft, increased gradually from a height of about 170 ft, reaching as much as 40 kt at heights of 100～50 ft. The wind increased about 20 kt in 5 seconds.

3.2.5.7 Wind and Control Operation from a height of 50 ft to touch-dpwn
From a height of about 50 ft, the right crab angle and the right roll attitude angle began to be reversed, and subsequently the engine thrust (EPR) was somewhat reduced, but immediately thereafter, at a height of 40 ft and near the runway end, CAS decreased 12 kt in a second down temporarily to 146 kt, being followed by start of decrease in the pitch attitude angle and increase in the descent rate.
According to the estimation of wind in para. 3.1.4.2, the wind, which had reached 40 kt at heights of 100～50 ft, suddenly weakened together with a significant change in the direction, and at a height of 40 ft became temporarily a tail wind, where the longitudinal component of the wind varied about 12 kt between heights of 50 ft and 40 ft (about one second in time).
The roll to the left and the yaw were considerably abrupt, and about 2 seconds prior to touch-down the aircraft was brought to the wing-level with the heading coincident with the runway bearing.

In order to restrain overshooting, at three seconds before touch-down the control wheel was operated to the right, and two seconds before touch-down the rudder was reversed to the neutral position. The left roll and the left yaw, however, did not stop, and in order to suppress them the control wheel was operated more extensively with a maximum reaching as much as 50 degrees. By this operation the angle of the right spoilers (No.2 to No.6) increased. The angle of No. 2 spoiler reached 45 degrees at 1.5 seconds before touch-down.

Around this time the aircraft's descent rate was rapidly increasing. Although the control column was operated about 5 degrees aft at 1.5 soconds before touch-down at a height of 20 ft, it was about one second thereafter, which was 0.7 second before touch-down, that the nose began to be brought up, and the aircraft touched down with a left bank, the descent rate not being decreased.

3.2.5.8 Situation at the time of touch-down
The situation of the aircraft at the time of touch-down is estimated to have been as follows:

Descent rate	21 ft/second
CAS	157 kt (Note 1)
Maximum vertical acceleration	> 2.5 g (up) (Note 2)

Maximum lateral acceleration	> 0.25 g (left) (Note 2)
Pitch attitude angle	5.2 degrees (Note 1)
Roll attitude angle	-4.4 degrees (Note 1)
Yaw angle	-5.3 degrees (Note 1)

As shown above, the descent rate at touch-down is estimasted to have increased to 21 ft/second. It is 2.1 times as much as the limit descent velocity (10 ft/second) which is prescribed in the airworthiness standards (aircraft transport category airplanes) for structural design.(ground loads)

(Note 1) A value at the time the vertical acceleration would have reached the maximum.

(Note 2) The maximum vertical acceleration and the maximum lateral acceleration at touch-down were unreadable because errors existed at the portions in DFDR where their maximum values would have been recorded. (see para. 3.1.1). It is, however, estimated that they would have been larger than 2.5 g (up) and 0.25 g (left), respectively, judging from readouts before and after the errored portions.

3.2.5.9 Touch-down Point

It is estimated that the aircraft touched down at a point 230 meters inside of the approach end of the runway, and, after making one bound, touched down again about 2 seconds thereafter.

3.2.6 Rapid increase in descent rate and roll to the left immediately before touch-down

3.2.6.1 Cause for Rapid Increase of Descent Rate

The rapid increase in te descent rate is estimated to have been caused as follows:

(1) The aircraft encountered temporarily a tailwind at a height of about 40 ft, and its CAS decreased abruptly. The lift decreased due to this abrupt decrease in CAS, and the descent rate began to increase.

(2) CAS recovered almost normal 2.5 seconds before touch-down, but, as stated in para. 3.2.5.7, the operation of the control wheel was increased in order to restrain the left roll, with the result that the angle of the right spoillers (No.2 to No.6) increased. The angle of No.2 spoiler reached as much as 45 degrees as for No. 2 at 1.5 seconds before touch-down. By this spoiler operation, the lift of the right wing decreased considerably, and the descent rate rapidly increased.

(3) At a height of about 20 ft the control column was operated about 5 degrees aft, but it was the time the spoiler angle reached a maximum, and an abrupt decrease in lift by the spoiler operation gave rise to an abrupt increase in descent rate, with a result that the angle of attack and its

increase rate became larger and the nose-down moment thereby cancelled out the nose-up moment by the stabilizer; and therefore it was 0.7 second before touch-down, at which time the right spoiler angle became small, that the nose began to be brought up. For this reason, the descent rate ceased to increase, but could not be reduced.

(4) A possibility is conceivable that a very local downdraft caused by eddies might have contributed to the increase of the aircraft's descent rate, but existence of such an air current could not be clarified.

3.2.6.2 Left Yaw Rate and Right Side Slip

With regard to the reason that the operation of the control wheel to withhold the roll to the left was taken as reaching a maximum of as much as 50 degrees, it is estimated that the operation to the left of the rudder at the time of decrab was large, the delay in the timing to reverse it gave rise to a large yaw rate to the left as well as a side slip to the right, and a negative rolling moment was generated therby.

3.2.6.3 Control Operation immediately before touch-down and contribution of the wind to rapid increase of descent rate

As stated in para. 3.2.6.1 and the preceeding paragraph, it is estimated that an excessive use of the rudder to the left at the time of decrabing and the operation to withhold the roll caused thereby would have been deeply related to the abrupt increase of the descent rate immediately before touch-down.

It is conceivable that should the captain had carried out more properly the decrab operation, the aircraft would not have been led to a hard landing; It is, however, also conceivable that there was no other alternative for the captain to take to cope with such complicated wind variations the aircraft encountered at a low altitude as stated in paras. 3.2.5.6 and 3.2.5.7.

3.2.7 Cause for damage to the root of the rear spar of the left wing

It is estimated that the damage on and around the root of the rear spar of the left wing was caused as follows:

The accident aircraft touched down firstly with the left main gear at an abnormal large descent rate, and as a resullt of an excessive touch-down load caused thereby, the left wing rear spar web was shear-fractured in the vicinity of the wing root, and the rivets connecting the upper and the lower spar cap with the rear spar web were shear-fractured up to the vicinity of IWS 300. Therefore, rigidity around the rear root portion of the left wing was reduced greatly, allowing a large-scale deformation leading to damage to the spar cap and the fitting, buckling of the rear spar web, deformation of the upper skin, damage to heads of the rivets, etc.

3.2.8 Recognition of abnormality, transmission of related information, and fire-fighting and rescue activities

3.2.8.1 Initial Request of Fire Services by Captain

The captain, who received the request to stop the aircraft and advice on shutting engines down from the ground control who observed the aircraft seemingly leaking fuel, and also monitored a message from another aircraft "smoke coming out", directed the copilot to contact the ground control for fire services, and subsequently for a tug.
The request to the ground control was made about 0515:30 UTC, but was unreadable as a whole to the controller due partly to fast speed of its transmission, but no request for re-transmission of the message for confirmation was made because the controller was asked immediately thereafter coordination on use of taxiway from another controller, and besides, communications cut in with other traffic.
It is estimated that at this time, both the flight crew and the controller did not recognize the situation as an emergency, although they were cognizant of the abnormality of the aircraft.

3.2.8.2 Recognition of Abnormal Situation, Request of Fire Services and Dispatch of Fire-fighting Vehicles

Thereafter, the captain, who saw an amount of fuel flowing out through the left window, requested again the ground control to dispatch fire services, shutted all engines down, and dictated an emergency evacuation using the passenger adress system.
The controller could not comprehend well this transmission from the captain on fire services request due to interference with transmission with other traffic, but he requested assistance of the senior controller in charge of supervising overall services with a recognition that the situation was an emergency. The senior controller, who saw immediately thereafter the emergency evacuation being initiated, decided to take the emergency procedures, notified to all units concerned that the runway be closed, and at the same time requested the Control Room of the Fire Station of the Airport Authority to dispatch the fire services team.
Upon receipt of this request, a Class 1 Order (the alert order) was issued to the fire station and its satellite from the Control Room, followed by a Class 2 Order (the emergency order) in response to the second request from the tower for fire services.
It is estimated that the fire fighting trucks arrived at the site about 0523 UTC which is 7～8 minutes after the time the first request was made to the ground control by the aircraft.
It is considered that the reason why a somewhat longer time was required for the fire fighting team to arrive at the site after the fire services had been requested would be that the transmission and confirmation of the information was not conducted quickly and accurately between personnel concerned, besides delay in their recognition of the emergency situation.

3.2.8.3 It is recognized that the fire fighting trucks, upon arrival at the site, started without delay to take fire prevention measures by dispersing foam extinguisher.

3.2.9 Emergency Evacuation from the aircraft

3.2.9.1 The flight crew and cabin attendants had received the training on the emergency procedures set forth by the Cathay Pacific Airways, and it is estimated that each of the flight crew and cabin attendants guided passengers for evacuation in this accident in accordance with the established procedures.

3.2.9.2 Cause for Longer Time required in Evacuation
It is estimated, from statements of related personnel, that in this accident about 6 minutes was required for emergency evacuation, and the reason why such a longer time was required would be that only R1 and R2 escape slides were usable in the beginning, that R1 was damaged and became unusable because it leaned sideways when about one hundred passengers had evacuated out, and furthermore that most of passengers were less cognizant of the emergent situation with slow response thereto and many of passengers intended to bring their baggage out with them in the evcuation.

3.2.9.3 Deployment of Escape Slides in Strong Wind
The design and test standards of the escape slide of the aircraft prescribe its normal deployability in the maximum wind of 25 miles/hour (21.7 kt). It is, however, recognized from records of the runway 34 wind sensor located about 1,250 meters SW of the place where the aircraft came to a stop, that the wind then was an average of 23 kt from SW involving a gust with maximum of 38 kt. From these, it is estimated that the wind at that time which was exceeding the design standard would have been responsible for R3, R4 and L1 escape slides' becoming unusable immediately after they were deployed, and R1 escape slide's becoming flapped by the wind while in use and unusable, as well as the damage to R1 and R4 slides successive thereto.

3.2.9.4 It is estimated that the two passengers who were seriously injured in this accident were injured during the emergency evacuation.

4 Probable Cause

It is estimated that immediately after the aircraft, which was approaching in a crosswind varying extensively in direction and speed, initiated a decrab operation, the aircraft encountered such a change of the wind that the strong wind which had been blowing crosswise at a right angle until immediately therebefore suddenly decreased and temporarily turned to a tailwind, wherein the captain could not conduct a relevant landing operation with a result of giving rise to a hard landing.

Attached Fig. 1

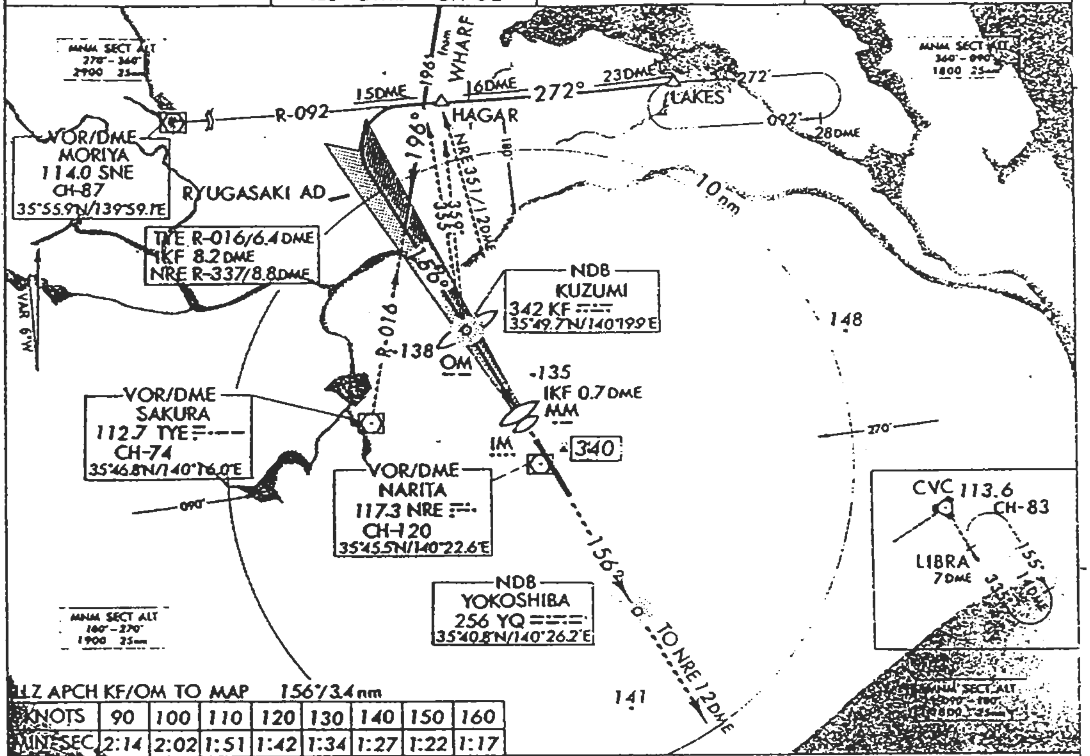
[New Tokyo ILS Runway 16]

Instrument Approach Procedures

AIP JAPAN
RJAA

NEW TOKYO ILS RWY 16

NARITA APP	ILS-LLZ	NARITA TWR	RADAR AVAILABL
125.8-124.4-261.2	111.5 IKF ILS-GP 332.9 ILS-DME CH-52	118.2-122.7-126.2 236.8-121.8G-121.9G	ATIS 128.25

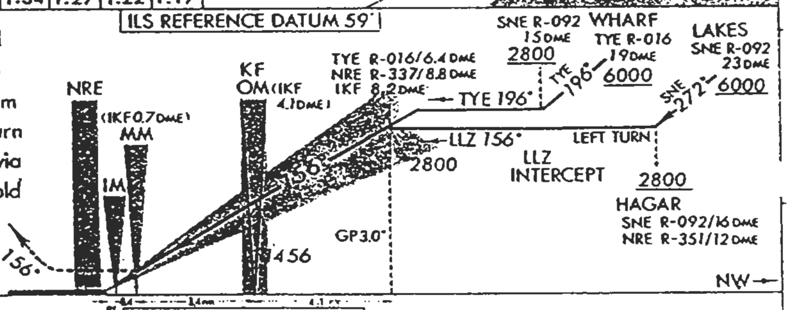


LLZ APCH KF/OM TO MAP 156°/3.4nm

KNOTS	90	100	110	120	130	140	150	160
MIN:SEC	2:14	2:02	1:51	1:42	1:34	1:27	1:22	1:17

ILS REFERENCE DATUM 59'

MISSED APPROACH
At DA, climb via 156° to YQ NDB and via 156° from YQ NDB, at NRE 12 DME turn left to CVC VORTAC, then via CVC R-155 to LIBRA and hold at 6000'.
Contact NARITA APP.



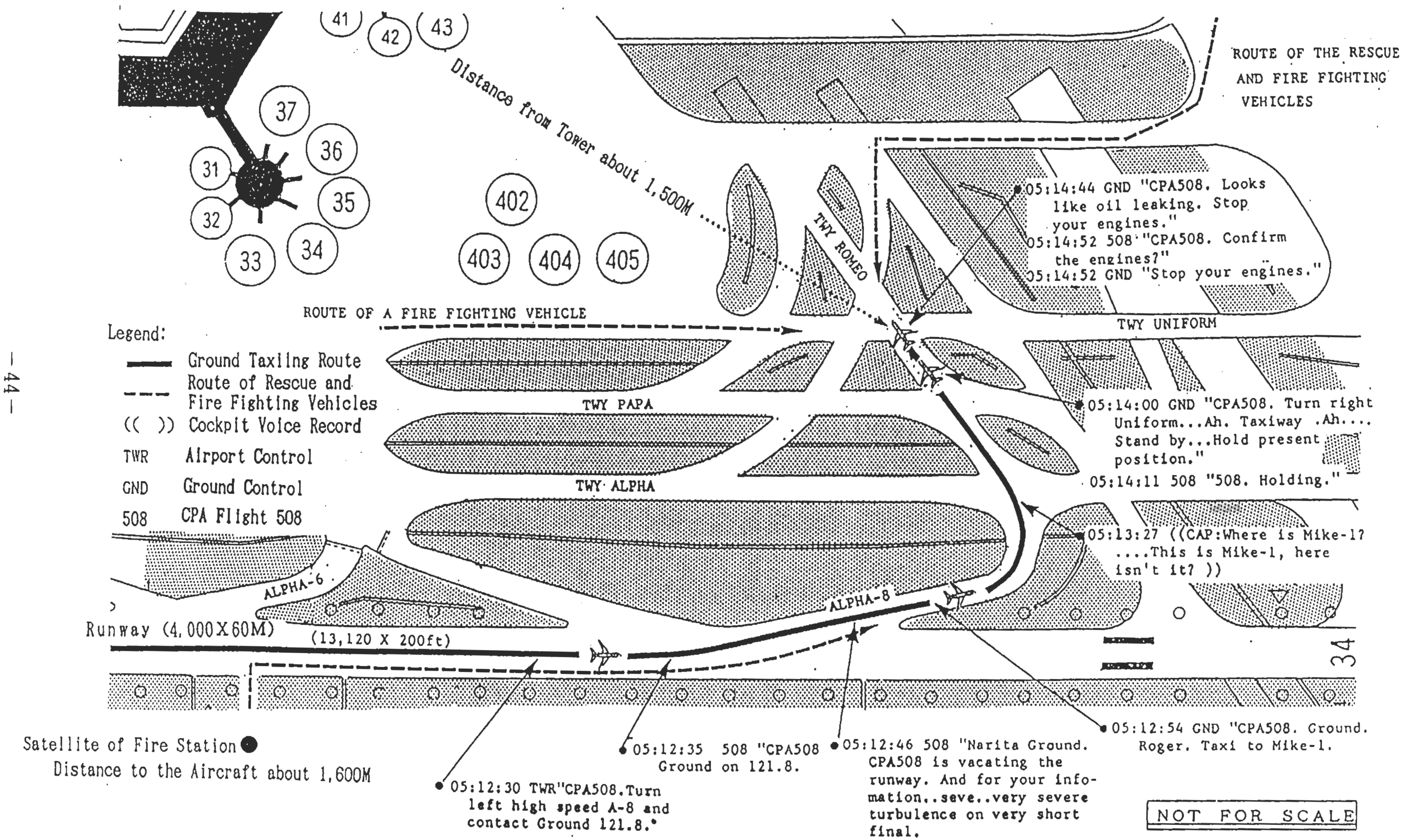
FIELD ELEV 135ft
TDZ ELEV 130ft

MINIMA

	CAT II RA 154' DA 280'	STA TO RWY 16 DA 330' FULL ILS TDZ & RCL LGT AVBL	TDZ &/or RCL LGT OUT	ALS OUT	DA 380' MM OUT	MDA 480' GP OUT	GP & ALS OUT	CIRCLING MDA-VIS
A	RVR 500m	RVR 600m VIS 800m	RVR 800m VIS 800m	RVR 1200m VIS 1200m	RVR 1000m VIS 1000m	RVR 1200m VIS 1200m	RVR 1400m VIS 1400m	640'-1600m
B								
C								640'-2400m
D					RVR 1200m VIS 1200m		VIS 1800m	700'-3200m

35°46'N-140°23'E

Attached Fig. 2 Taxiing Route and Cockpit Voice Record (an abstract)



Attached Fig.2

Transcription of CVR Records after VR-HOC stopped (abstract)

note : GND=Ground Control 508=CPA508 《 》 Intra-Cockpit Voice

(TIME:UTC) (CONTENTS)

05:14:58 《 CAP; Yeah. OK. Shut down. Get the APU on line? •••••Okay,start the APU quickly, please.》

05:15:11 BAW "Ground,Speedbird 8. Is the Cathay Tristar on this frequency?"

05:15:15 BAW "Considerable smoke coming from the left hand undercarriage of the Cathay Tristar....Unaware of it."

05:15:26 《 CAP; Can we have the fire service, please?"》

05:15:28 508 "CPA508. Request the fire services coming up to the aircraft on stand by."

05:15:36 《 CAP; And we need a tug to pull us in, please.》

05:15:39 508 "CPA508. We would like a tug, as well, to tow us in."

05:15:43 《 CAP; Get the chief purser up, say stand by for evacuation.》

05:15:50 《 F/E; Can you prepare, just get ready no panic at the moment for an evacuation••••• [unreadable] ••••》

05:16:10 《 CAP; Oh, we've got a lot of fuel coming out of the left hand side......We need fire trucks, fire trucks!》

05:16:15 BAW "And Cathay Tristar. There is really considerable smoke coming from....It looks like left hand wing fuselage area. Fuselage root............."

05:16:24 508 "Thanks. We got a fuel spillage. We need the fire trucks in attendance straight away please."

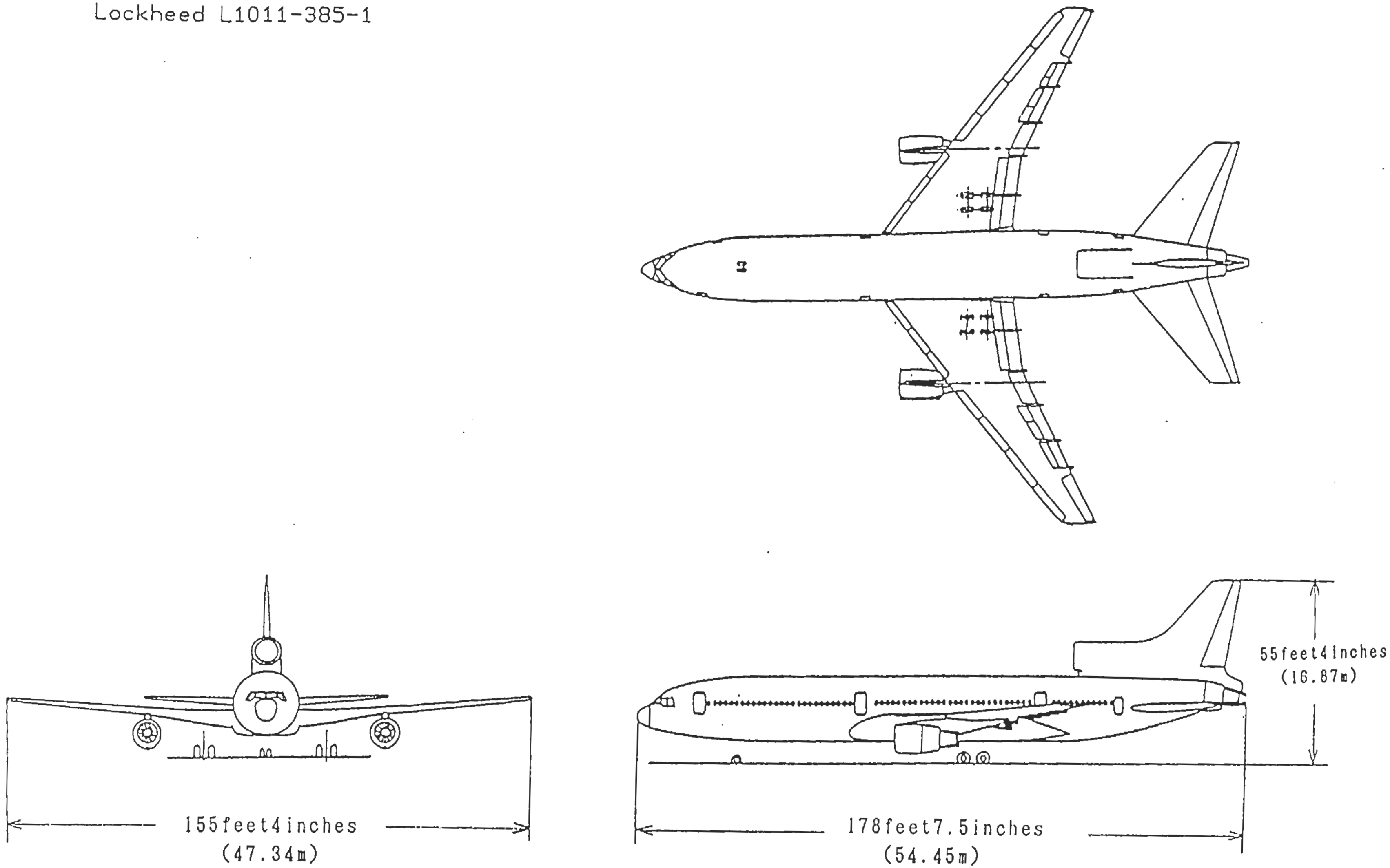
05:16:28 GND "CPA508.Now you stopped all engines?"

05:16:34 508 "All engines are stopping. Thanks."

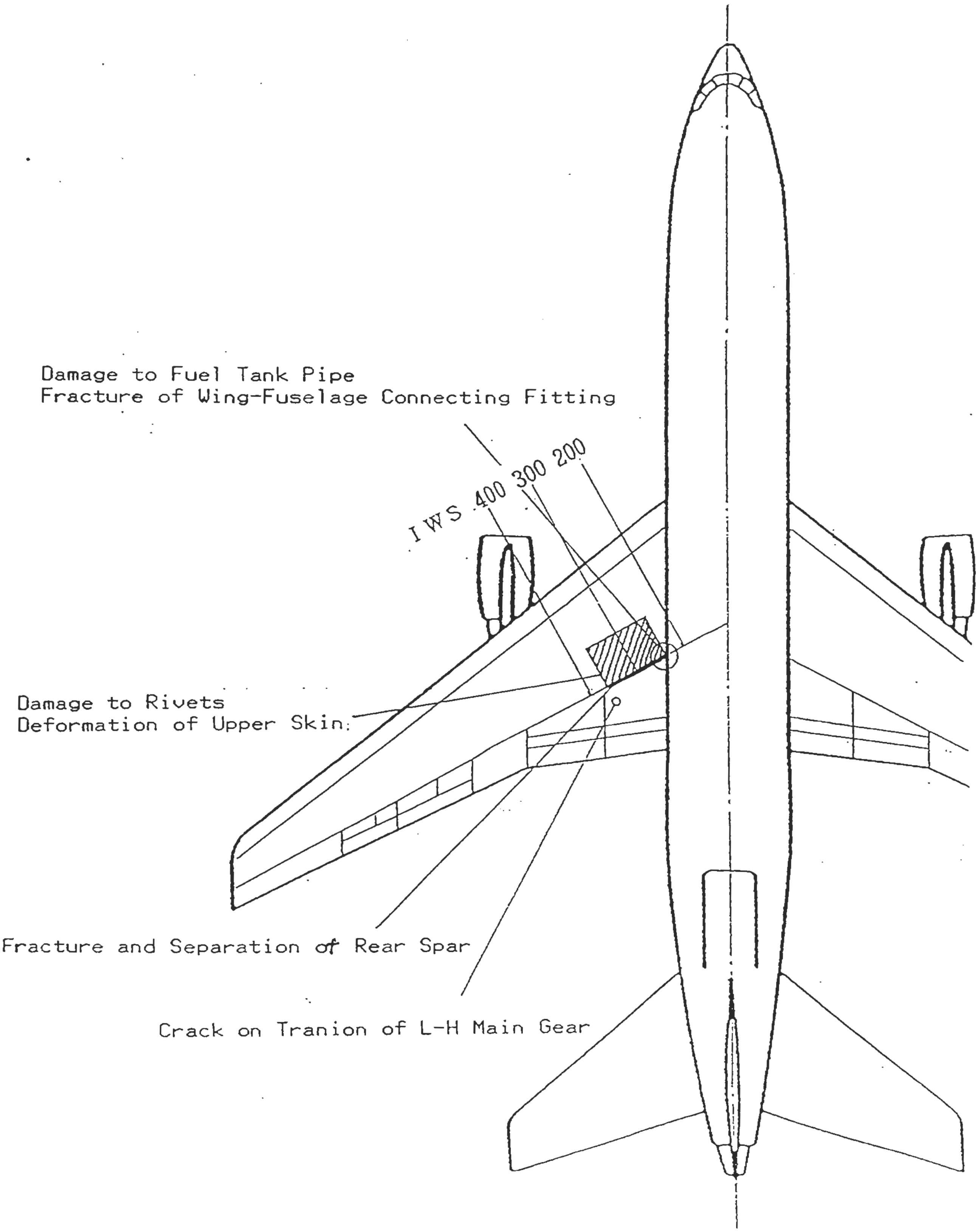
— End of Recording —

Attached Fig. 3

Lockheed L1011-385-1

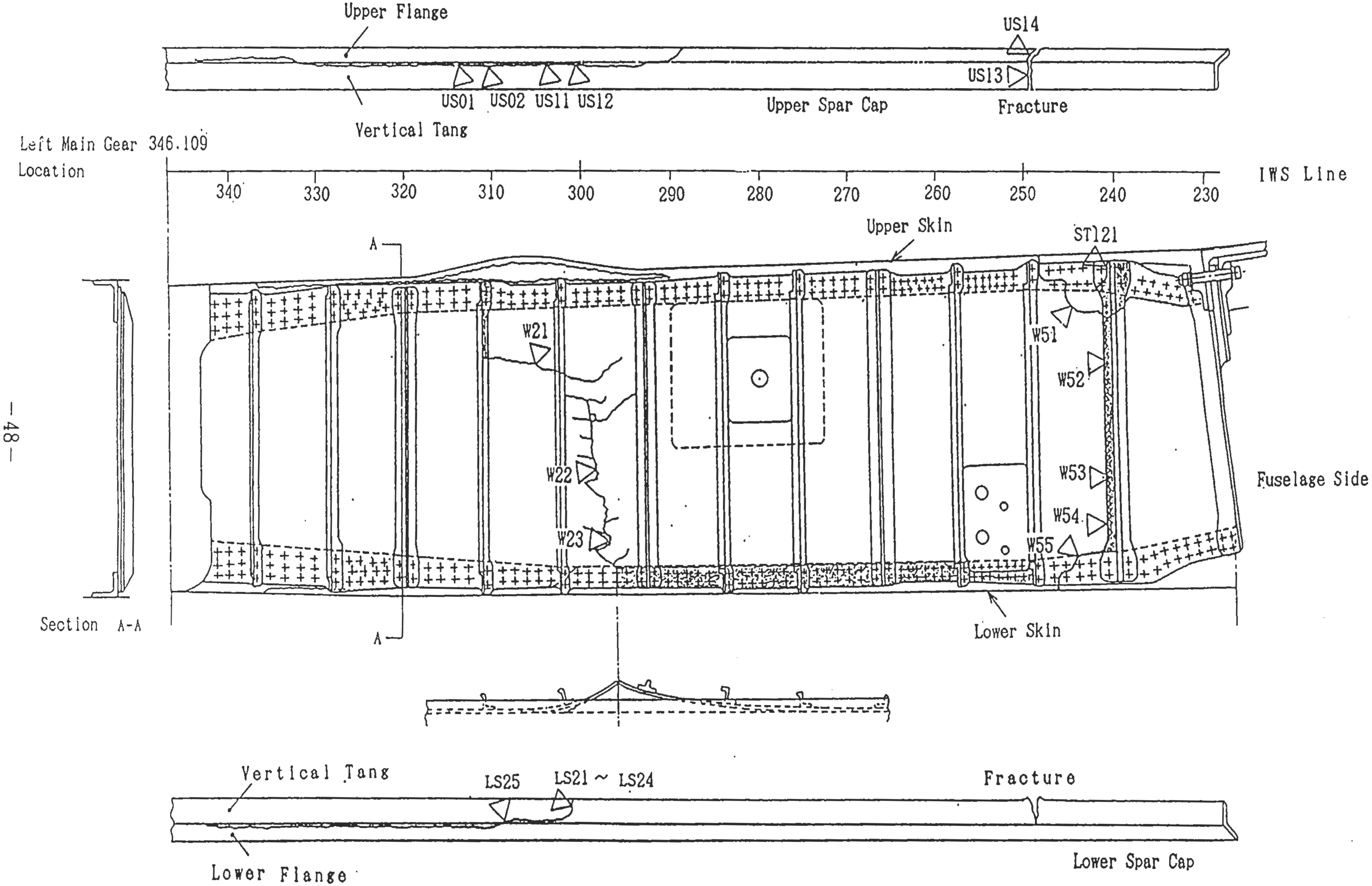


Attached Fig. 4 Damage to Airframe



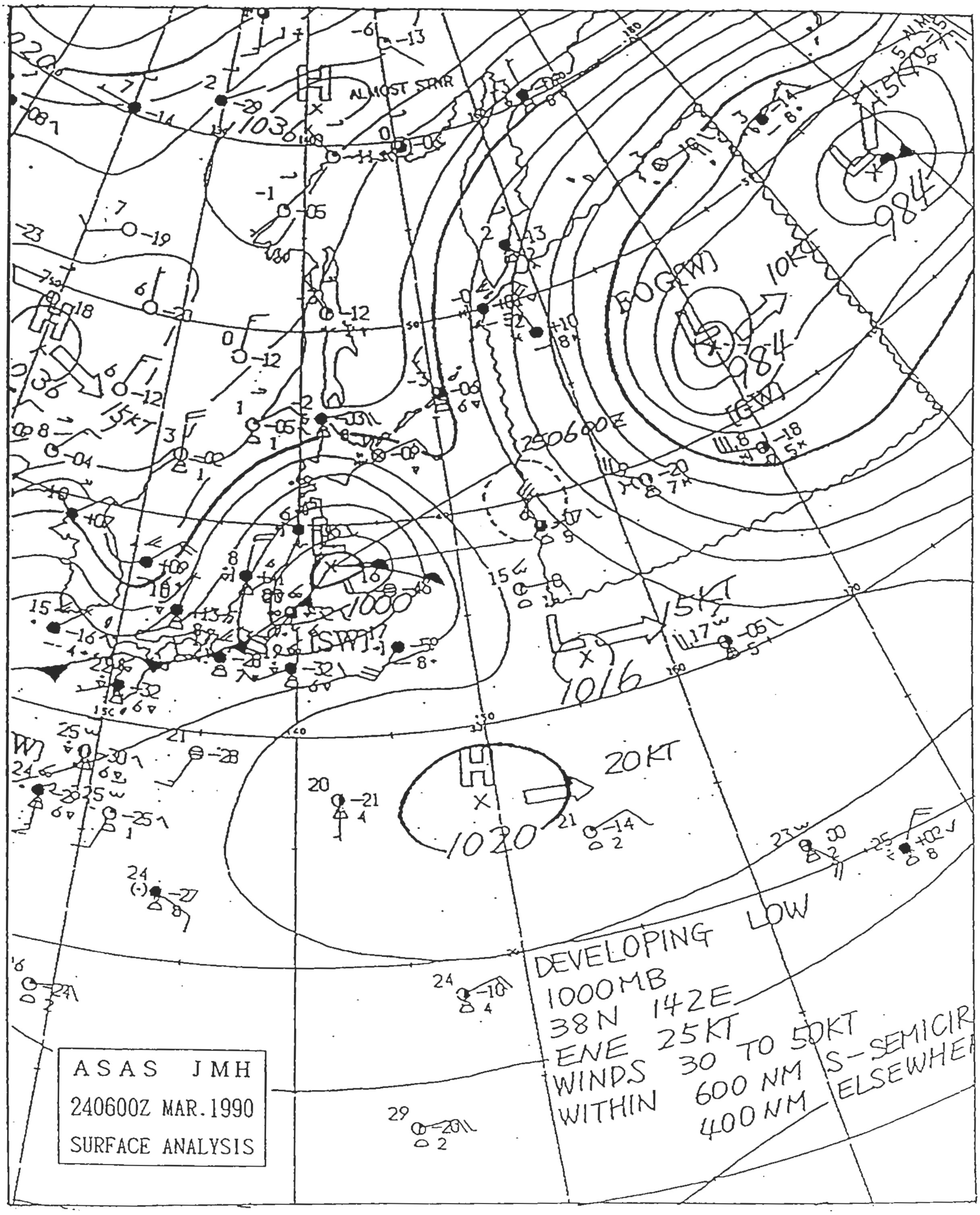
Attached Fig. 5

Damage to Neighborhood of Root of L-H Wing Rear Spar



Attached Fig. 6 Surface Chart

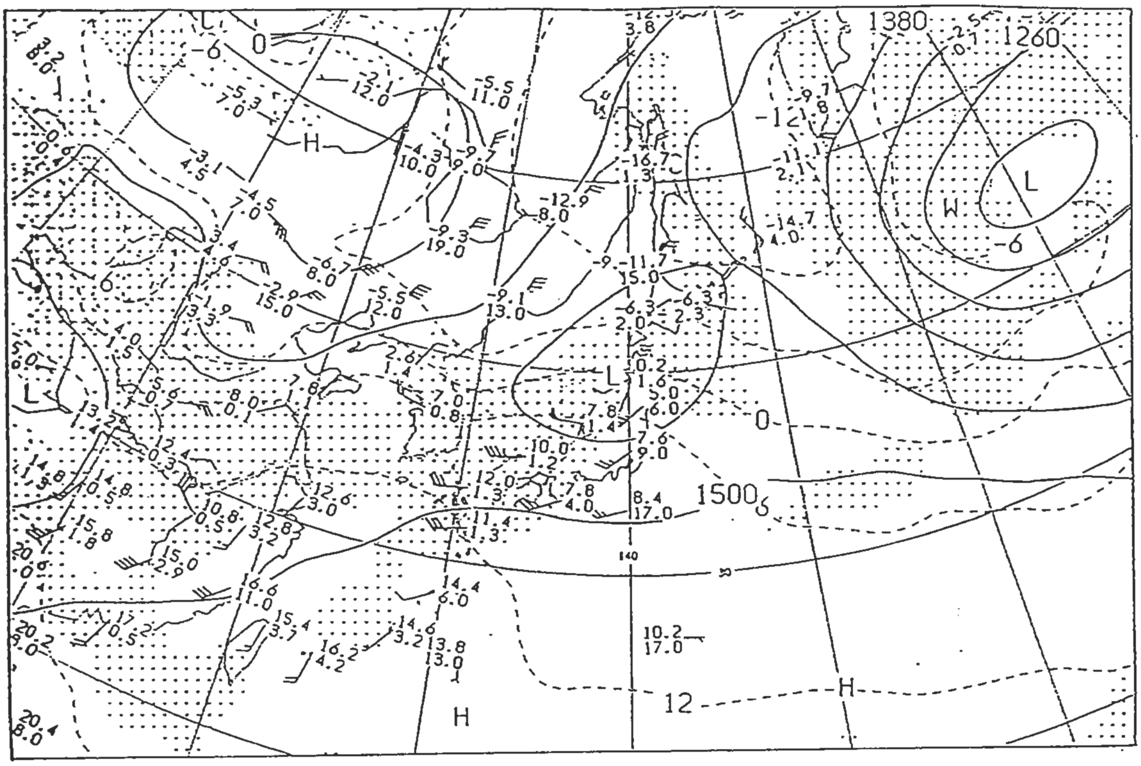
0600 Hours (UTC), March 24, 1990



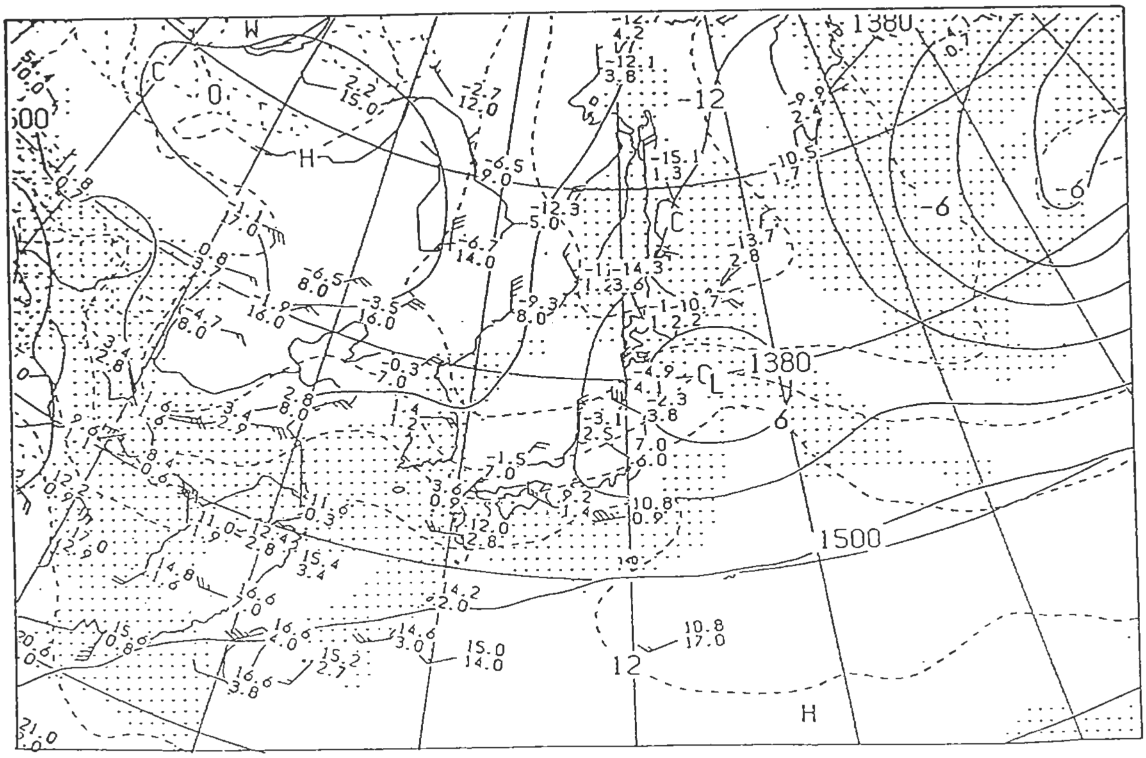
Attached Fig.7 850 hPa Chart 0600 and 1200 Hours (UTC), March 24, 1990

Solid line indicates contour; broken line isotherm; stipple region where dew point depression (t-td) is less than 3° C; and upper figure beside station temperature (in degree C).

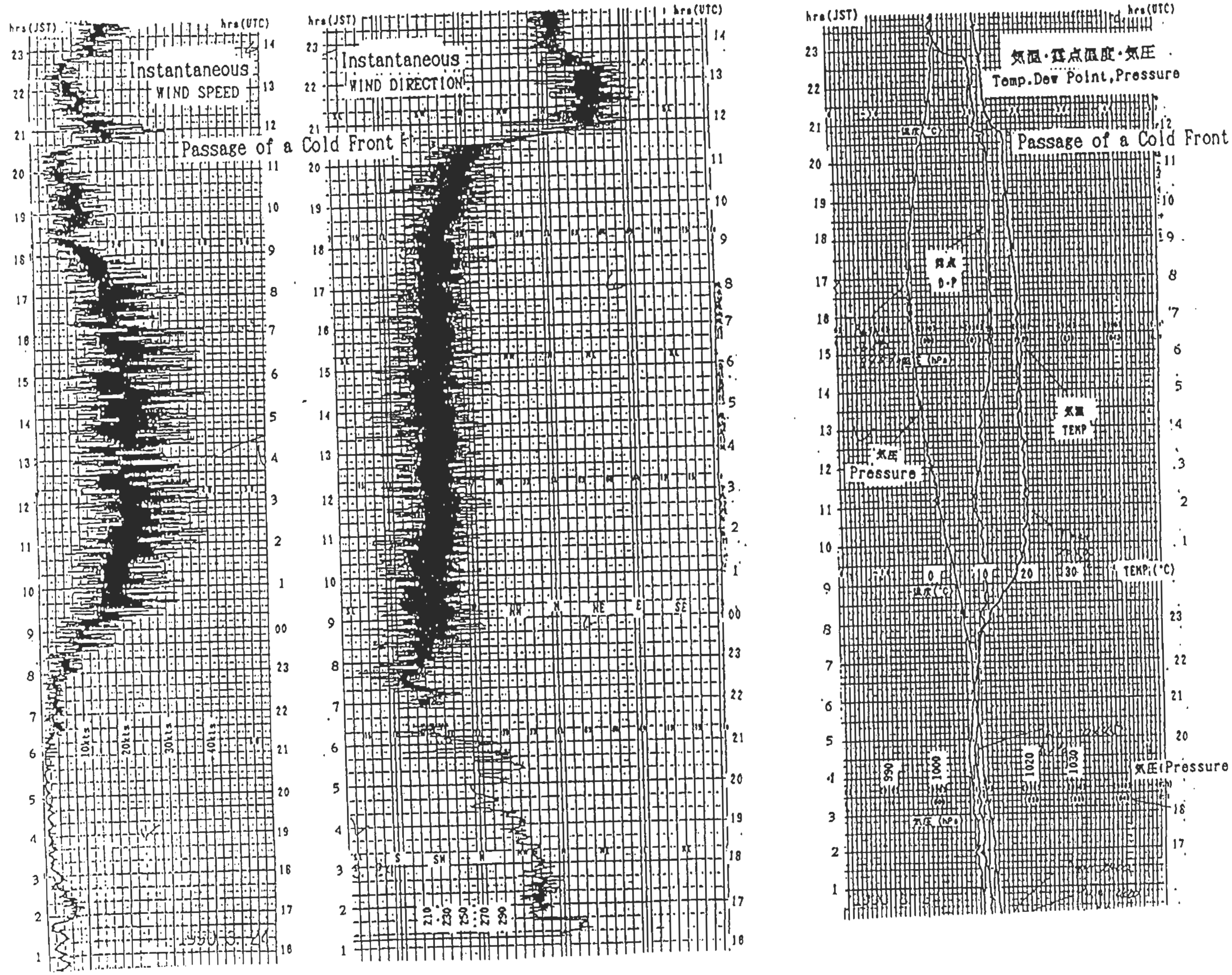
AUPQ85 24/0000 UTC



AUPQ85 24/1200 UTC



Attached Fig. 8 Records of Wind Direction/Speed, Temperature, Dew Point, and Pressure at Runway 34 March 24, 1990



Attached Fig. 9

Local Chart of Wind and Temperature
0500 hours (UTC) March 24, 1990

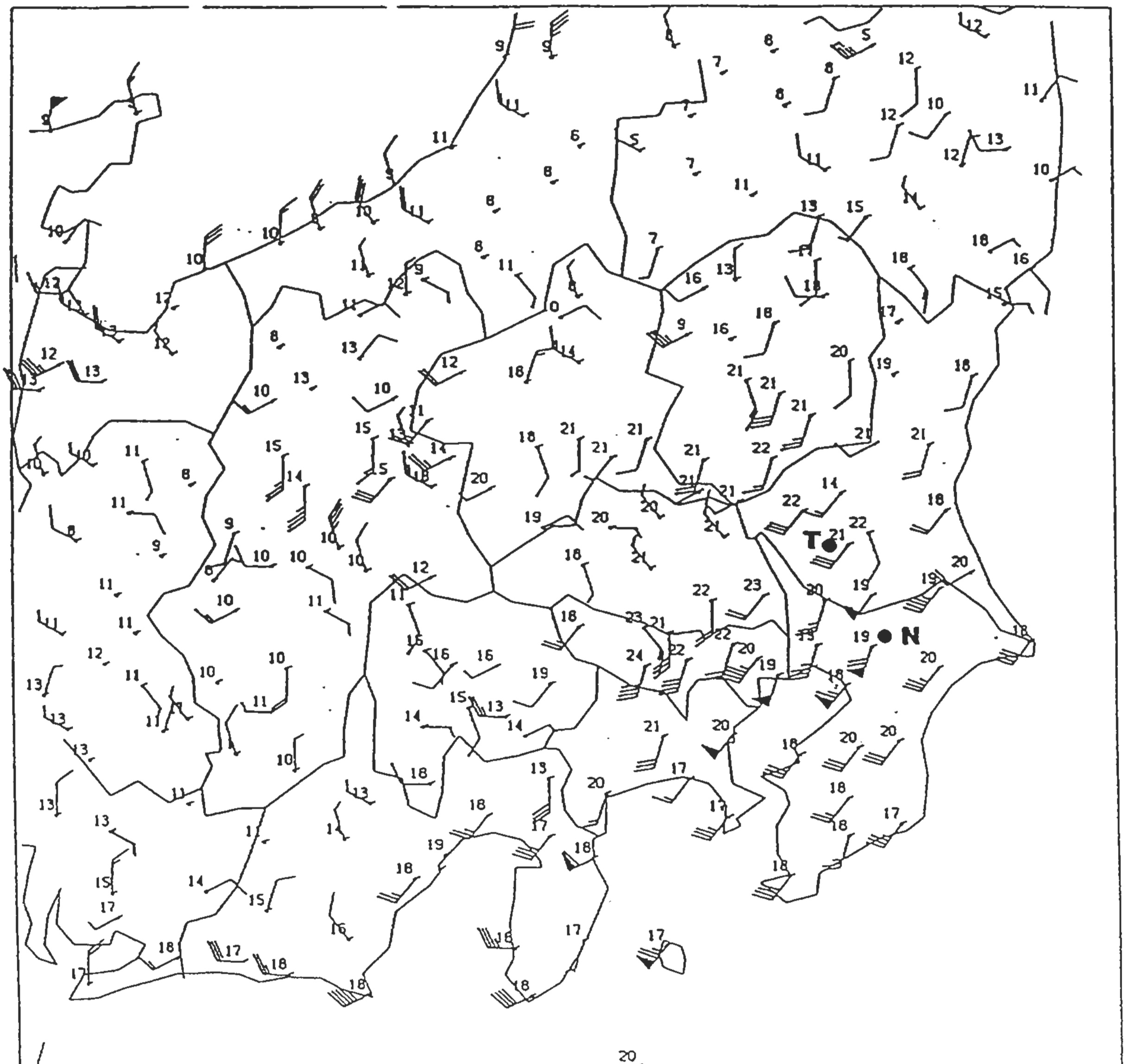
Figures indicate Temperature (in °C)

T: Meteorological Research Institute (Tateno)
N: New Tokyo International Airport (Narita)
Wind: Wind Speed

Wind: Wind Speed 10m/s

Wind Speed 2m/s

Wind Speed 1m/s

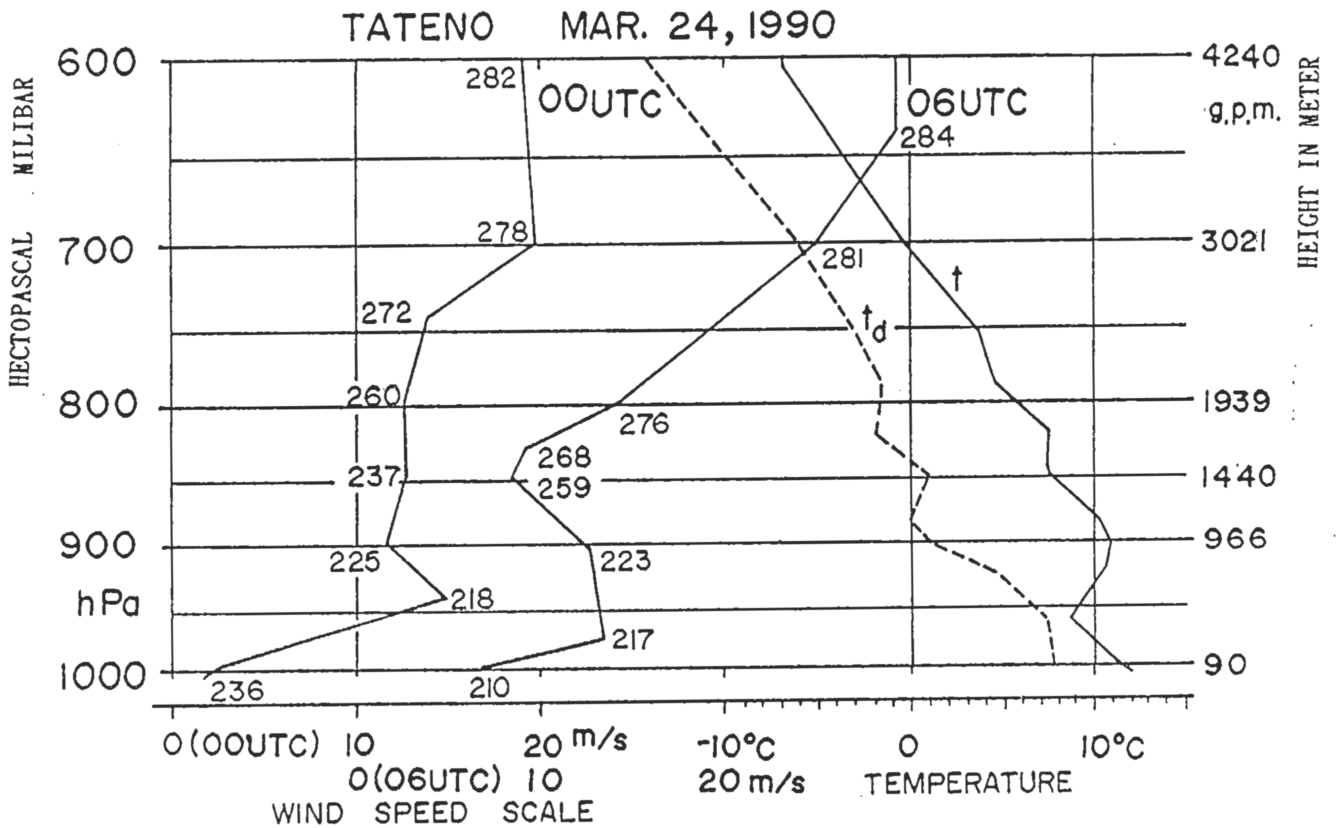


Attached Fig. 10

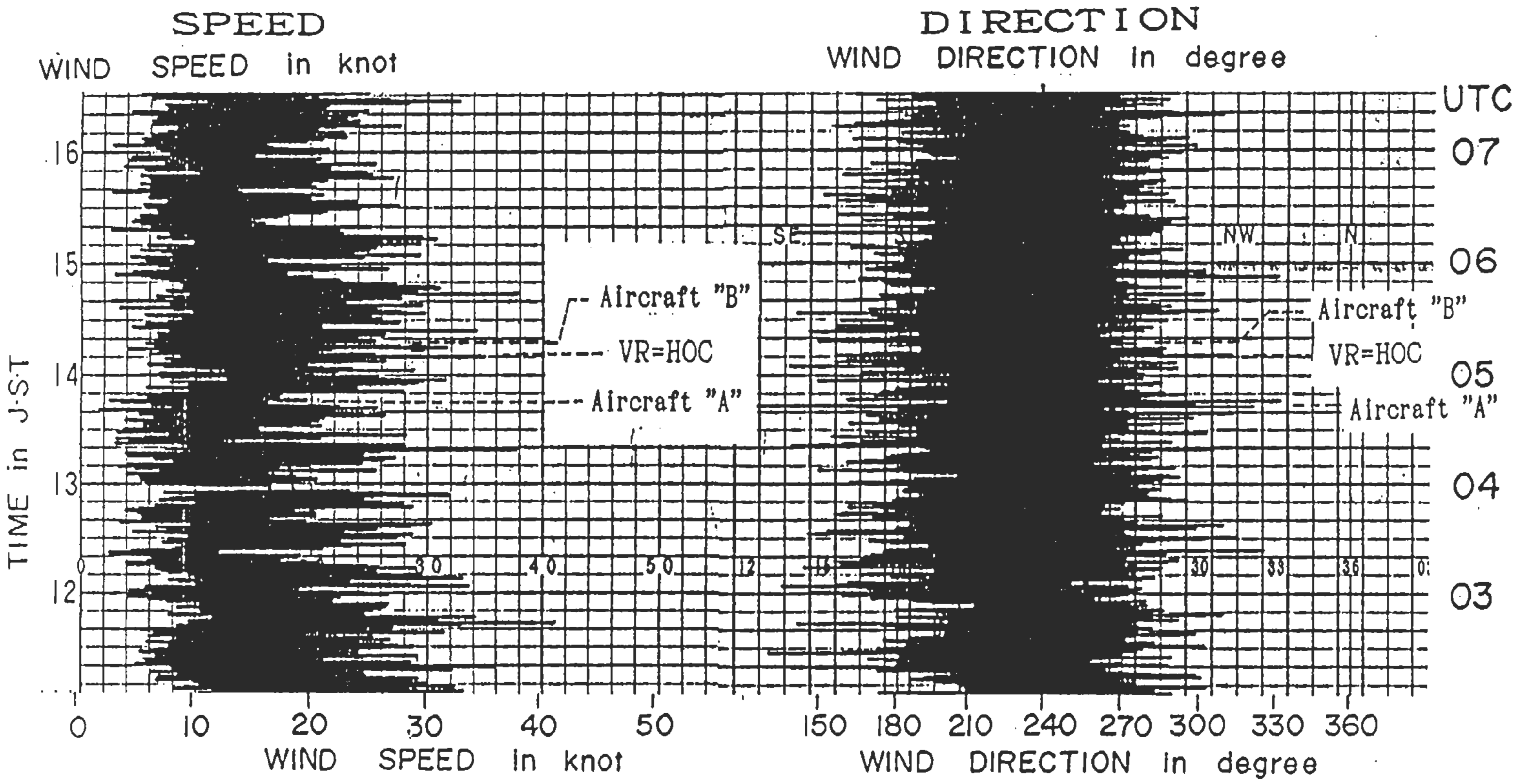
Sounding Curves of Temperature, Dew Point Temperature and Wind at Tanteno 0000 and 0600 hours (UTC), March 24, 1990

Left Side: Solid line indicates wind speed; and figures beside solid line wind direction. Origin of 0600 hours (UTC) curve shift from 0000 (UTC) curve to right 10 m/s in scale.

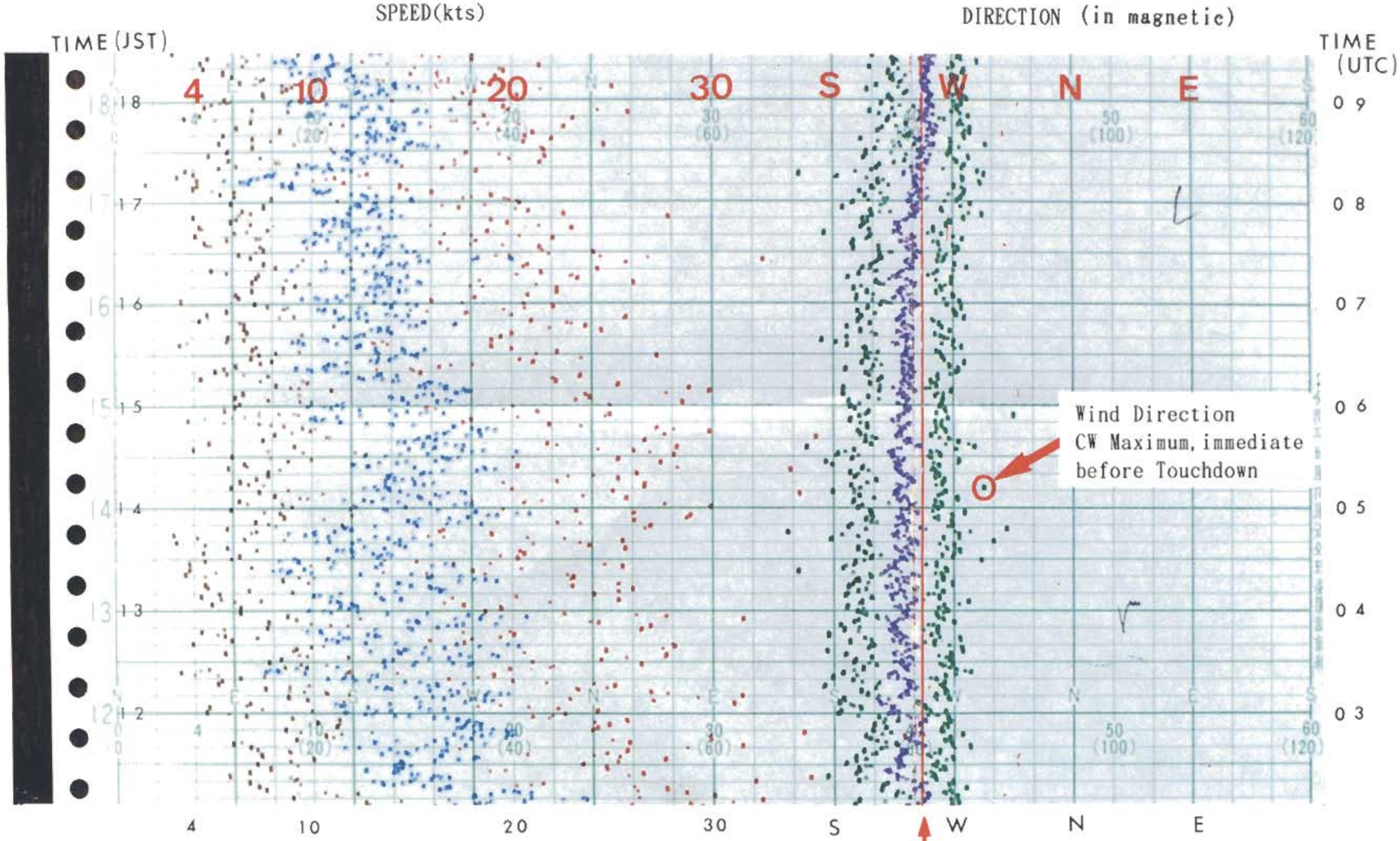
Right Side: Temperature (in solid line) and Dew Point (in broken line) at 0000 hours (UTC) are shown by curves.



Attached Fig. 11
Records of Wind Direction/Speed at Runway 16
0200 - 0700 hours, March 24, 1990



Attached Fig. 12
Records of TWO(2) Minutes Average of Wind Direction/Speed at Runway 16
March 24, 1990

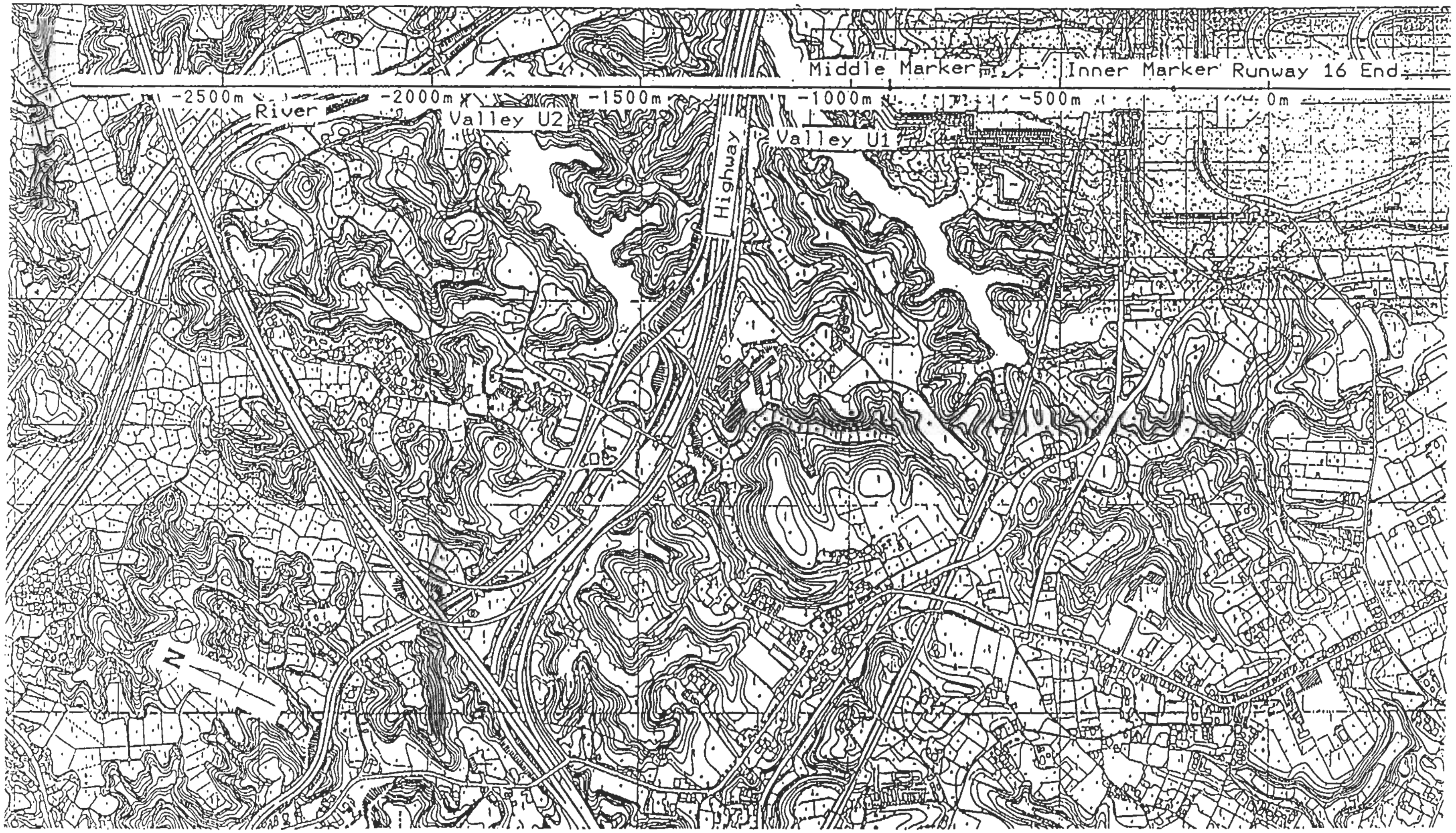


Wind Speed	Color	Wind Direction	Color
Minimum Wind Speed	Light Brown	Wind Direction CCW	Green
Average Wind Speed	Blue	Average Wind	Purple
Maximum Wind Speed	Red	Wind Direction CW	Green

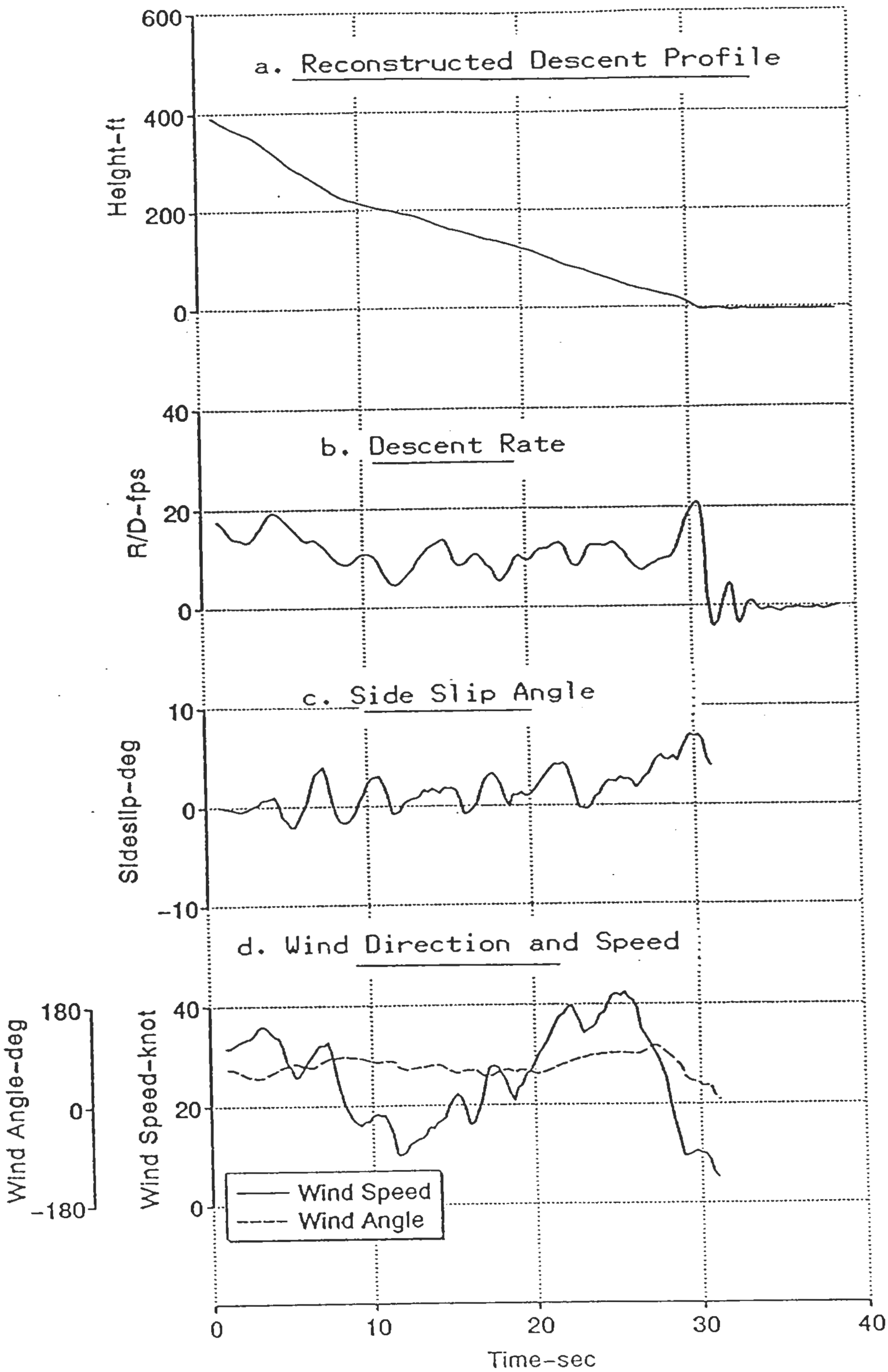
(Wind Direction CW Maximum or Minimum : Maximum or Minimum to clock-wise direction in reference to Average Wind Direction)
(Wind Direction CCW Maximum or Minimum: Maximum or Minimum to clock-wise direction in reference to Average Wind Direction)

Attached Fig. 13

Topographic Chart of Area in the vicinity of Final Approach Course to Runway 16

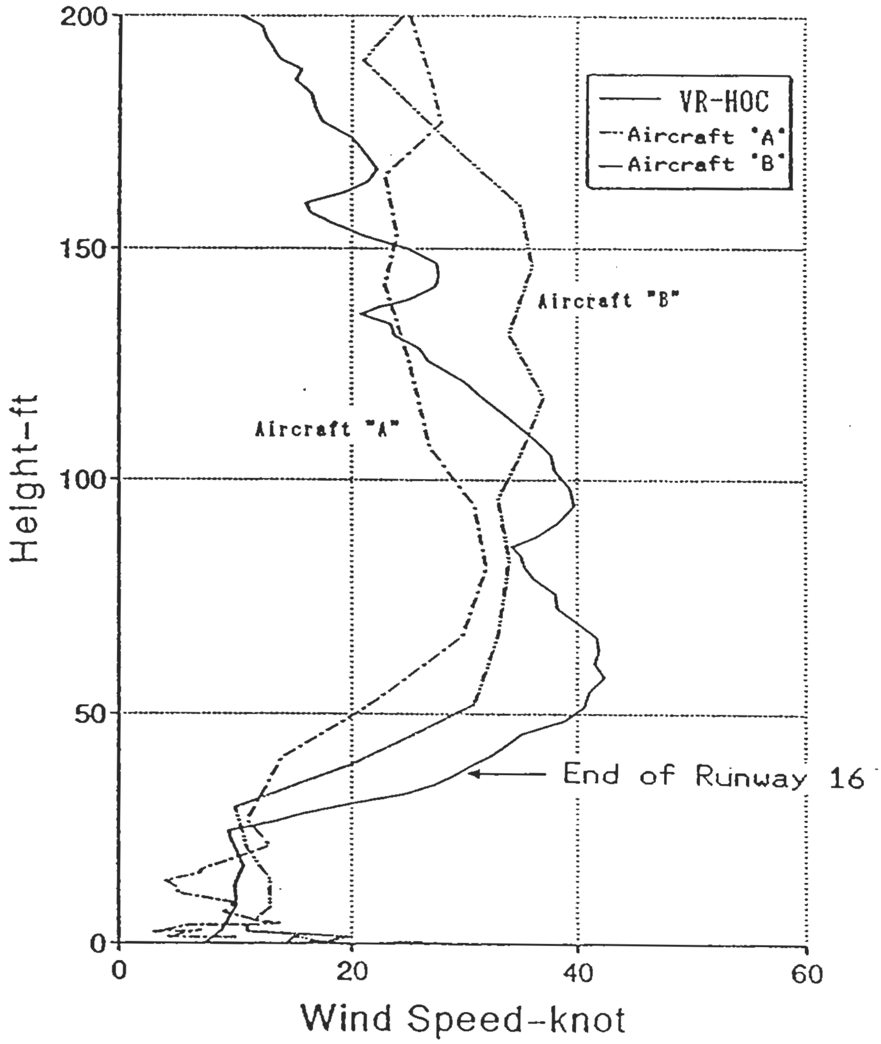


Attached Fig. 14:
Estimation of Descent Rate and Side Slip Angle



Attached Fig. 15

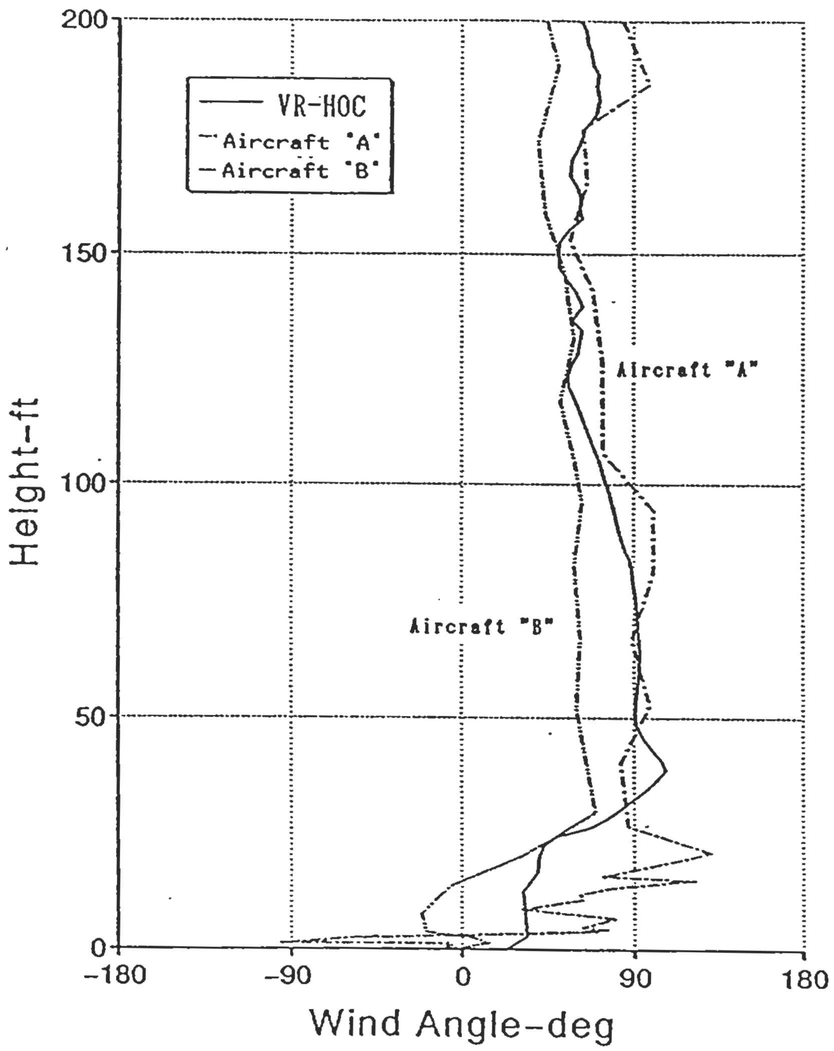
Variation of Wind Speed during Approach and Landing



Attached Fig. 16

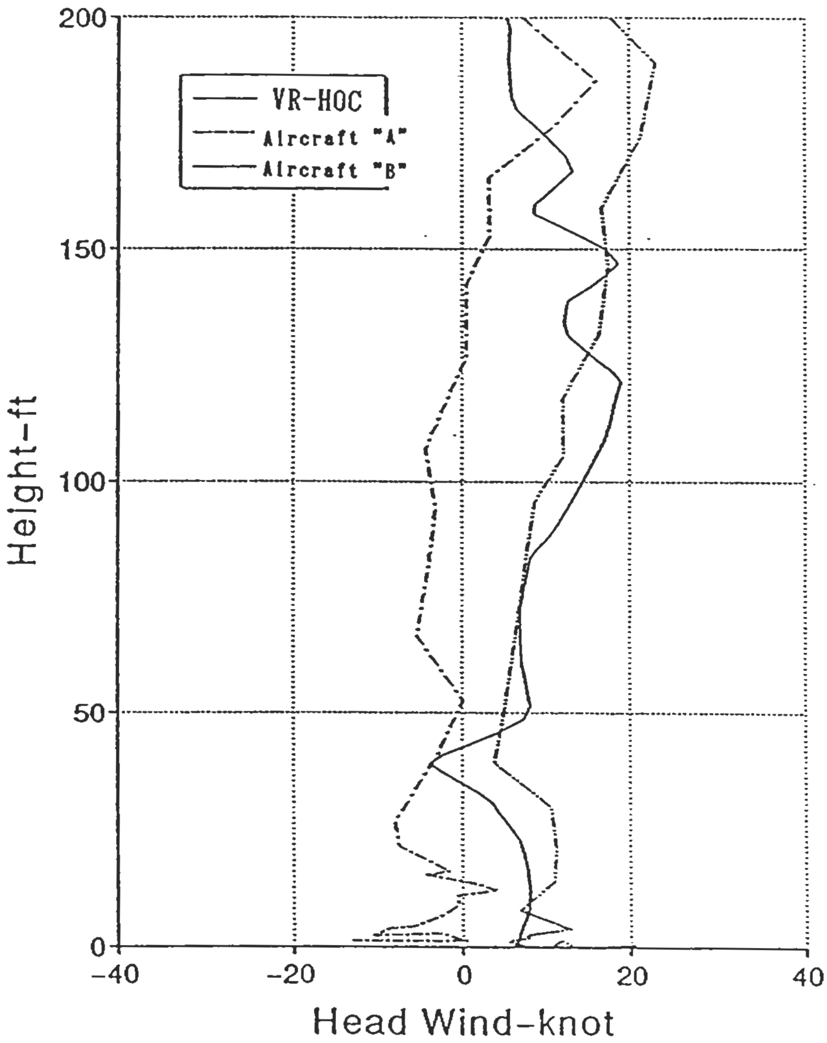
Variation of Wind Direction during Approach and Landing

(The direction of Runway 16 is taken as 0 degree)



Attached Fig. 17

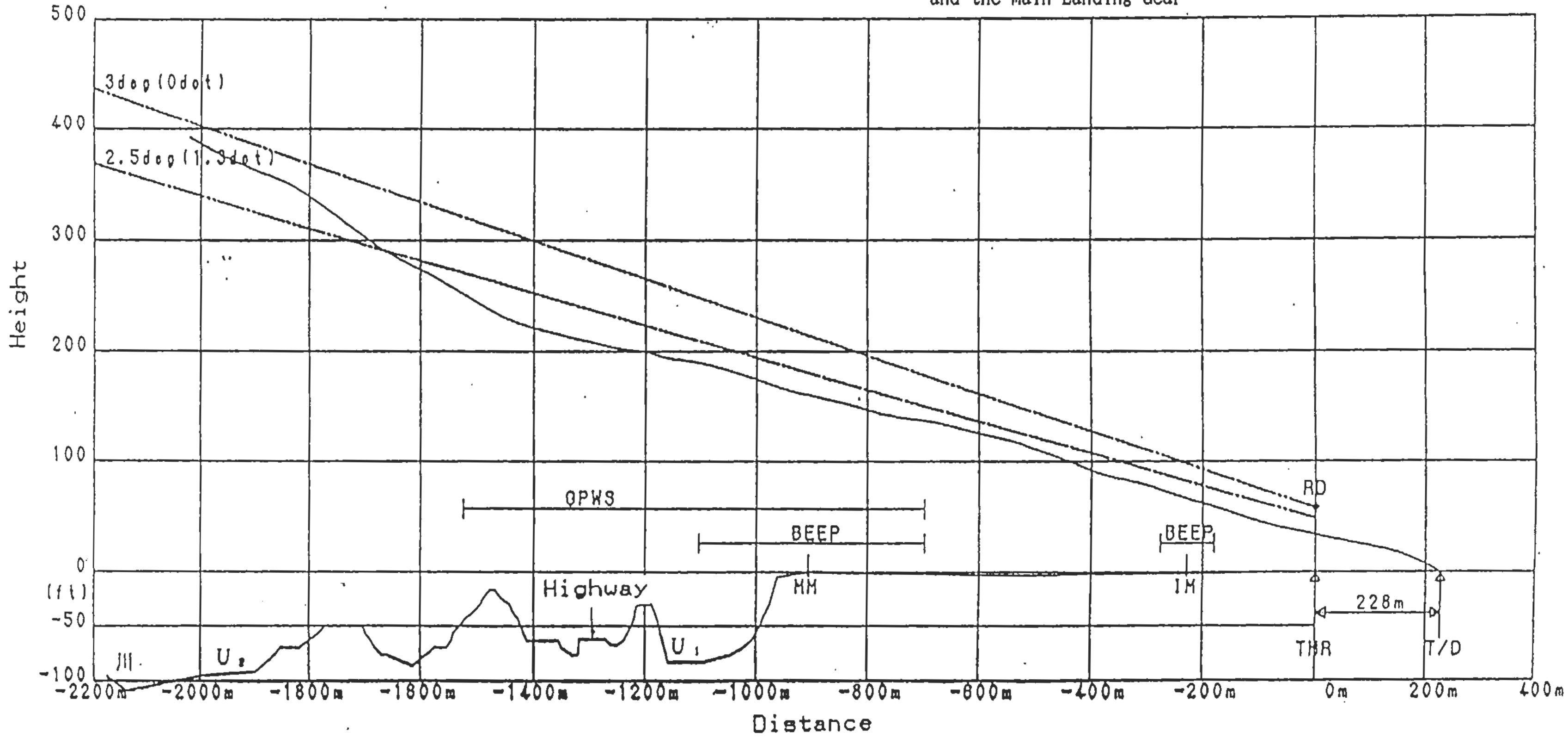
Variation of Longitudinal Component of Wind during Approach and Landing



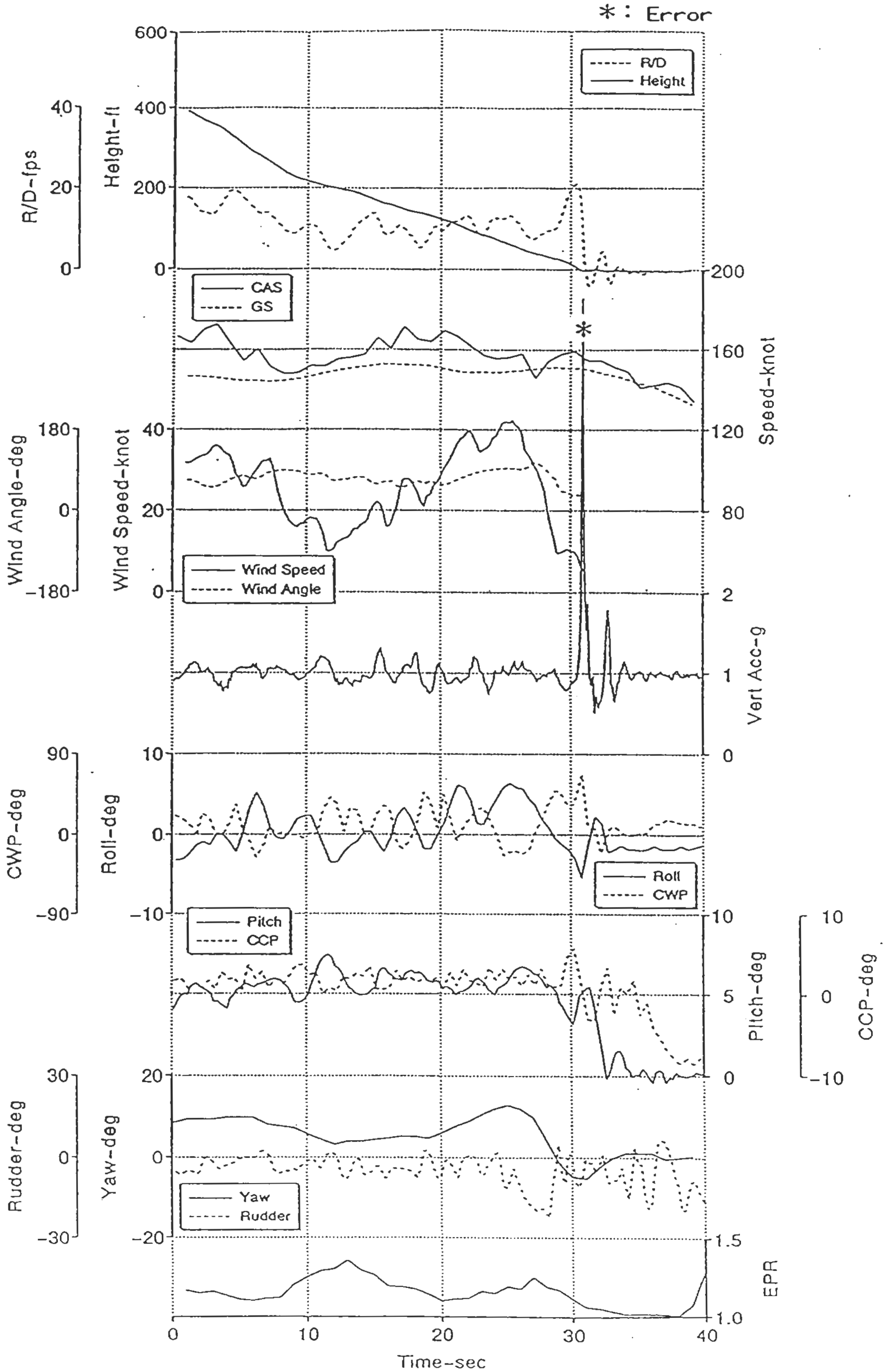
Attached Fig. 18 Estimated Descent Profile

T/D : Touch-down Point
THR : End of Runway 16
RD : ILS Reference Datum
IM : Inner Marker (228m from end of runway)
MM : middle Marker (908m from end of runway)
GPWS : Soft Warning Activative Sector of GPWS Mode 5
BEEP : Marker Activative Sector

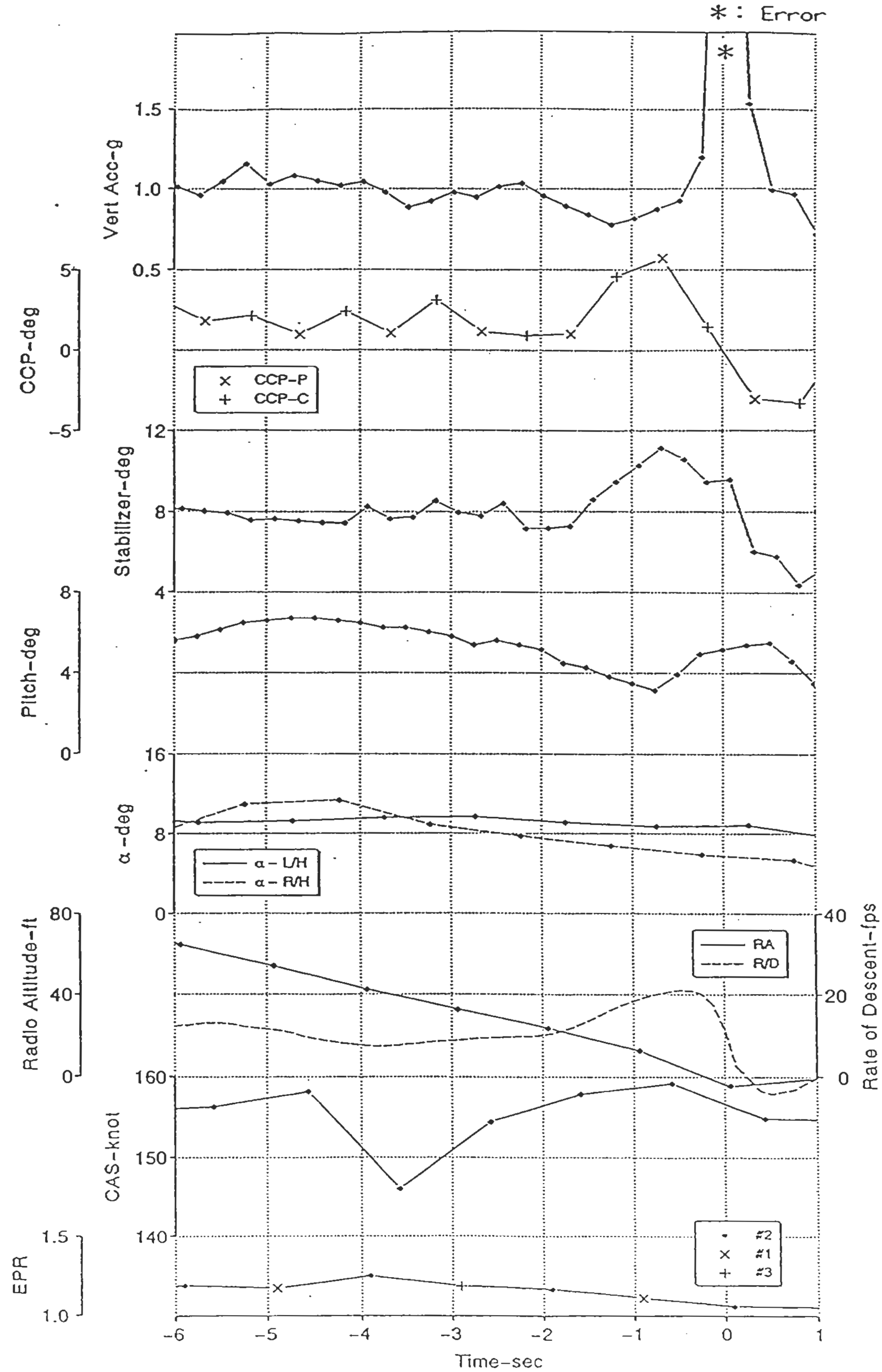
Height: Vertical Distance in Feet between the Touch Down Zone and the Main Landing Gear



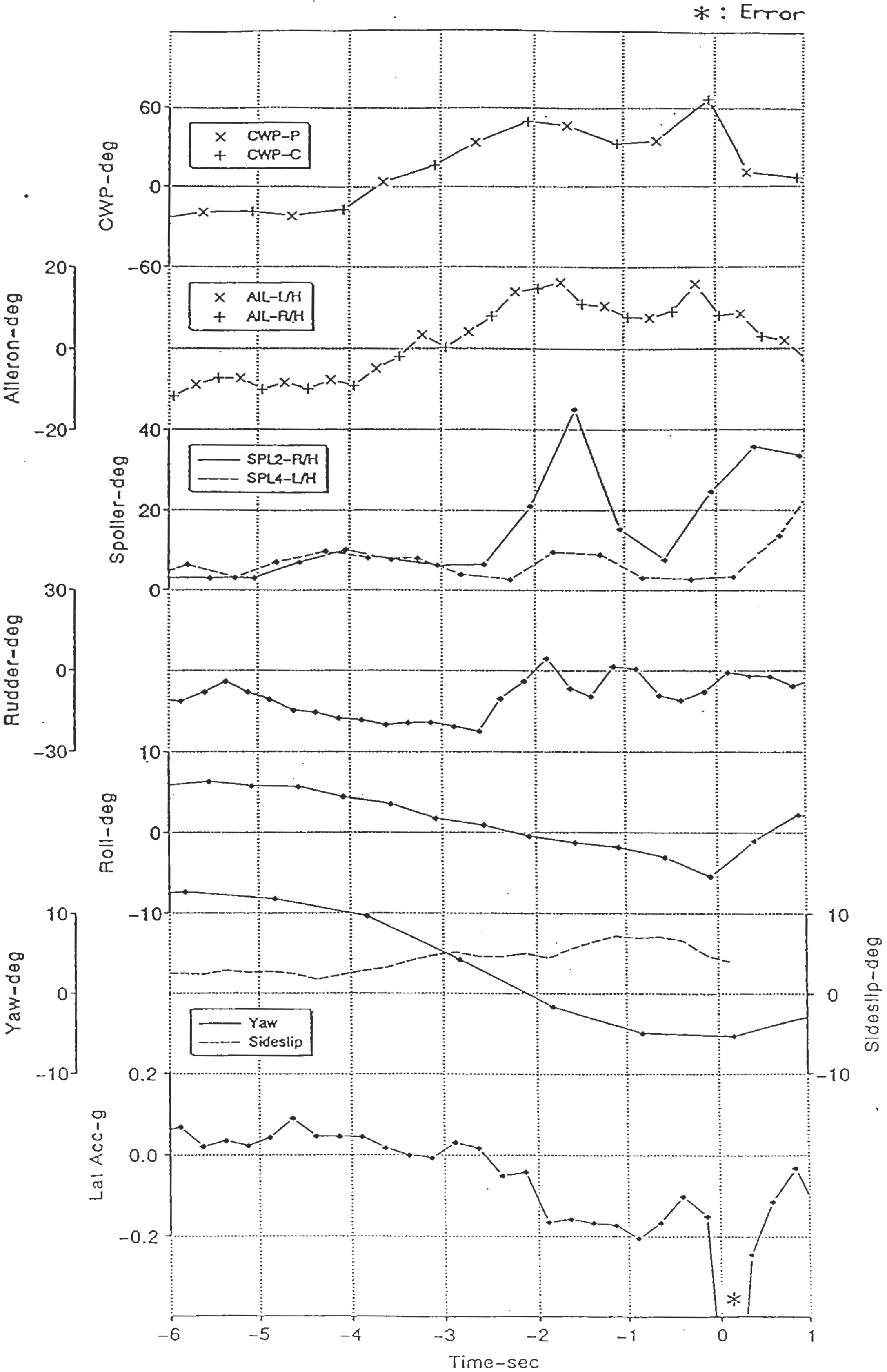
Attached Fig. 19 Chronological Records



Attached Fig. 20
Longitudinal Motion immediately before Touch-down



Attached Fig. 21 Lateral Motion immediately before Touch-down



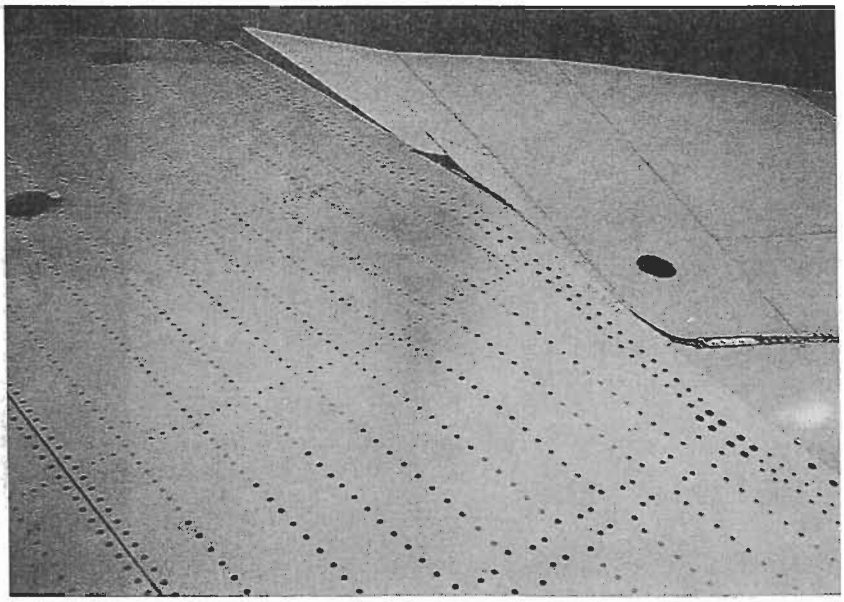
Attached Table 1　Gusting Rate

Gusting Rate: Rate between Instantaneous Maximun Wind Speed for every 20 minutes and Average Wind Speed for every 10 minutes (0300 - 0600 hours UTC, March 24, 1990)

	Runway 16				Runway 34			
Time (UTC) (hours and minutes)	Instantaneous Maximum Wind Speed (kt)	Time Appeared (hours and minutes)	Average wind speed10 minutes (kt)	Gusting Rate	Instantaneous Maximum Wind Speed (kt)	Time Appeared (hours and minutes)	Average wind speed10 minutes (kt)	Gusting Rate
03:00～03:20	33.0	03:04	14.0	2.4	41.0	03:04	23.0	1.8
～03:40	30.5	03:38	16.0	1.9	36.3	03:27	21.0	1.7
～04:00	32.0	03:53	14.0	2.3	37.5	03:49	23.0	1.6
04:00～04:20	38.0	04:19	15.0	2.5	43.0	04:02	21.0	2.0
～04:40	28.0	04:29	12.0	2.3	37.5	04:26	23.0	1.6
～05:00	31.5	04:58	16.0	2.0	38.0	04:56	22.0	1.7
05:00～05:20	35.0	05:10	15.0	2.3	36.0	05:04	23.0	1.6
～05:40	34.0	05:24	15.0	2.3	41.0	05:34	25.0	1.6
～06:00	38.0	05:44	16.0	2.4	38.5	05:50	19.0	2.0

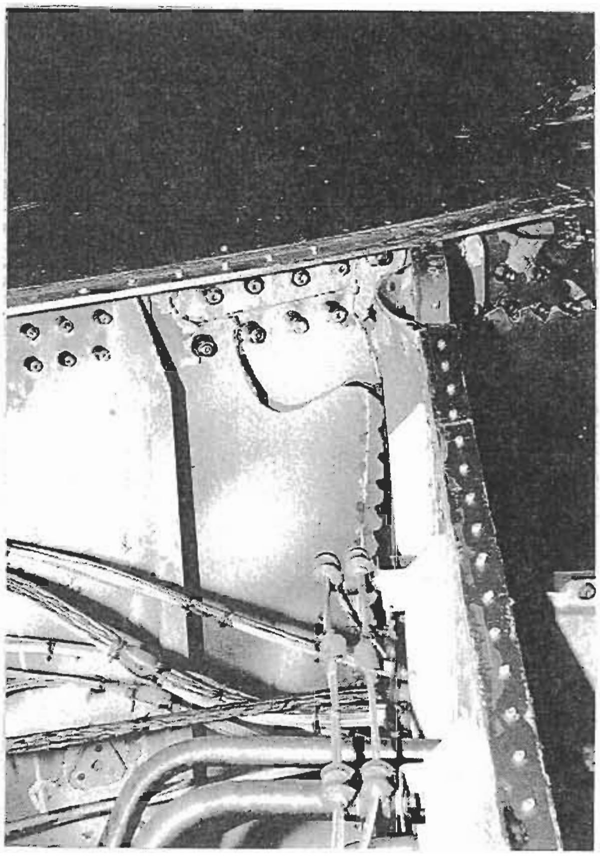
Photograph 1

Damage: Wing Upper Surface (L/H)



Photograph 2

Damage: Wing Rear Spar (L/H) (near IWS241)



Addendum 1 Estimation of the wind during approach and landing by surface wind and data recorded in other aircraft

1 Estimation of the wind during approach and landing of VR-HOC by surface wind

Since no records of the wind are included in the DFDR of the accident aircraft, the wind VR-HOC encountered on the glide path was estimated in the following ways, with reference to wind data recorded in an aircraft (Aircraft 'A') which landed 27 minutes before the aircraft, as well as another aircraft (Aircraft 'B') which landed 6 minutes after the aircraft.

The data of Aircraft 'A' and 'B' are those recorded before and after VR-HOC, but interpolation is inapplicable, because there were variations in wind direction and speed for a period of several to ten minutes. Therefore, the wind recorded in Aircraft 'A' and 'B' were compared with data of the runway 16 wind sensor. Since the winds recorded in Aircraft 'A' and 'B' were the winds what the aircraft encountered when they were in flight along the glide slope, at a height of 400～300 ft, for instance, it was about 2.5～1.8 km distant from the wind sensor located on the ground. However, if there is a correlation between the record on board the aircraft and the surface wind, the wind the accident aircraft encountered on approach and landing could be estimated from the record of the surface wind with reference to the wind recorded in Aircraft 'A' and 'B'.

The recording paper (see Attached Fig. 11 of the Text) of the runway 16 wind sensor is unable to read the average wind because the recording paper is saturated with recording ink. Therefore, the maximum value deviated to the north (not gust but an average for several minutes) was compared with the average wind recorded in the aircraft on the assumption that when the wind direction was diviated to the north, the average wind would also make a similar change. (see Attached Table 1) According to this,

(1) The wind direction observed by the runway 16 wind sensor deviated 30 deg more to the north at the time Aircraft 'A' landed than at the time Aircraft 'B' landed; while, at heights of 200～20 ft, the average wind direction observed by Aircraft 'A' deviated 24 deg more to the north than that by Aircraft 'B', the deviation being almost coincidental for the former and the latter.

(2) The wind speed observed by the runway 16 wind sensor, (of both the

2-minute and the 10-minute wind sensor), was 3 kt less at the time of Aircraft 'A' landed than at the time Aircraft 'B' landed; while, at heights of 200～20 ft, the mean wind speed observed by Aircraft 'A' is 4 kt less than that by Aircraft 'B', the difference being almost coincidental for the former and the latter.

Therefore it is possible to estimate from the runway 16 wind sensor the wind at the time VR-HOC landed. The wind conditions the accident aircraft encountered, as estimated by the above method, could be summarized as " the wind direction during the period VR-HOC was on approach to land was between that for Aircraft 'A' and that for Aircraft 'B'; while the wind speed during the period was higher than it was for Aircraft 'A' and was of almost the same level as for Aircraft 'B'".

2 Topography and abrupt change of the wind

2.1 Wind shear on approach path

The wind which Aircraft 'A' and Aircraft 'B' which landed 27 minutes before, and 6 minutes after the accident aircraft landed, respectively, are as shown in Attached Figs. 1a and 1b, where many places can be seen in which the wind was strong or weak.

At the right side of the chart is shown the height from the runway threshold. If this wind change had been caused by a vertical shear, the vertical shear for Aircraft 'A' would have reached as much as 34～48 m/s per 100 meters, while the existence of a vertical shear of such order should be inconceivable. Therefore, this characteristic wind distribution would be attributable to a horizontal variation due to the topography. For reference, it is noted that the vertical shear at the observing tower of the Meteorological Institute in Tukuba City (located at the same place as the Aerological Observatory) is 4.2 m/s per 100 meters at the time the accident occurred.

2.2 Determination of position of aircraft

Since the variation of wind and the topography are closely related to each other as stated above, it is necessary to clarify the relationship between the topography and the wind (CAS). For this purpose the position of the aircraft must be predetermined. The position of VR-HOC was determined by the method in para. 3.1.3.3 of the Text, while positions of Aircraft 'A' and Aircraft 'B' were obtained on the assumption that they were just over the inner-marker at the mid point of the period for which the marker-passing signal was recorded on board the aircraft. It is noted that the data in Aircraft 'A' and Aircraft 'B' are ones recorded for every second, and the distance, which is obtained from the ground speed between the middle marker and the inner-marker, minus the actual distance was -69 m for Aircraft 'A', and -24 m for Aircraft 'B'. The following discussions are within errors of such a scope.

3 Change in CAS of VR-HOC during Approach and landing and discussion

The chronological change in CAS of VR-HOC is described in the following.

3.1 Abrupt change in CAS in the vicinty of 1.5 km point from approach end of runway 16 (see Attached Figs. B1, B2, B3)

According to Attached Fig. 2, CAS was large in Sector EK (2.3～1.8 km from the runway threshold), and reached 172.6 kt at Point K. The similar trend can be seen for Aircraft 'A' and Aircraf 'B', too, in this vicinity. Since the representative wind in this vicinity is 225 deg/35 kt for Aircraft 'A', and 210 degress/45 kt for Aircraft 'B', the wind would be a headwind of 9 kt for Aircraft 'A', and a headwind of 22 for Aircraft 'B'.
This area is located near the point where Valley U2 running with a heading of 200 degrees crossed the flight course, and the surface wind therein would horizontally converge to increase the speed. However, since the flight altitude was about 400 ft above the hill, it is unknown whether the effect of the valley would have reached up to this height. Such a trend, however, can be seen in Attached Figs. 1a and 1b.

In case of VR-HOC, CAS decreased abruptly from Point K, and the amount of decrease for Point K to Point B3 reached as much as 25 kt in 5 seconds.

From Point F which is 3 seconds after CAS began an abrupt decrease, EPR increased, but, according to CVR, around this time the warning sound of GPWS's "glide slope" was activated. CAS is making a similar change also in case of Aircraft 'A' and Aircraft 'B'. According to the wind record of the two aircraft, in this neighbouhood the wind direction is deviated to the north for both aircraft, and therefore there would be a possibility that the wind direction was deviated to the north for VR-HOC, too.

Since the flight course in this sector where CAS made an abrupt decrease was lying on the leeward side of a hill of about 130 ft sea level, the abrupt decrease in CAS might be attributable to an influence of the topography.

3.2 Sudden change in CAS in the vicinity of middle marker (see G.H in Attached Fig. 2)

CAS of VR-HOC increases irrespective of decreasing EPR, and reaches a maximum over a plateau near the middle marker. The plateau is of such a topography as to make the wind blow up along a cliff on its windward side.

As for Aircraft 'A' and Aircraft 'B', there is an abrupt change in CAS at a point as indicated as G and H, respectively, in Attached Fig. 2 (the maximum of the variation is 12.7 kt/2 sec and 18.7 kt/2 sec, respectively) ; while as to VR-HOC, a similar change (at Point I) can be seen although the variation is very small.

This point is located on the edge of the airport near the middle marker, where the flight height is about 200 ft. The location (Point G or Point H), where change in CAS is significant, is having outsides of the airport boundary lying beyond about 200 meters on the windward side (i.e.,to the right facing the approaching direction) thereof, of such a complicated topography that there are sunken places and hills and, besides, a valley running at a heading of 200 degrees is crossing nearby. (see Attached Fig. 13 "Topographical Chart" of the Text)

With regard to the wind change in the vicinity of the steep slope on the north side of the middle marker (on the outer marker side), for Aircraft 'B' the wind speed reaches a maximum at a point about 1.0 km short of the runway threshold (Point P in Attached Fig. 1b); while for Aircraft 'A' the wind speed is shifting from a minimum to increase at the same point (P' point in Attached Fig. 1a) with a large variation in the wind direction herein.

The reason for this would be that for Aircraft 'B' the prevailing wind is about 215 deg (see Attached Table 1) and therefore the wind is blowing along Valley U1 running with a heading of about 200 degrees; while for Aircraft 'A' whose prevailing wind was about 239 deg, the wind direction does not coincide with the running direction of the valley.

Such an explanation to attribute the change in CAS at Points G, H and I in Attached Fig. 2 to an influence of the topography may be considered persuasive.

3.3 Abrupt decrease in CAS immediately before touch-down (see R in Attached Fig. 2)

After passing the middle marker, CAS of the aircraft decreases from near the midpoint between the middle marker and the inner marker. Such a trend can be seen for Aircraft 'A' and Aircraft 'B', too.

In case of Aircraft 'A' and Aircraft 'B', the wind suddenly decreases from near the inner marker. Since such a decrease would be inconceivable as a vertical shear, the abrupt decrease in the wind would be related to the topography. According to Attached Fig. 13 (Topogrpahical Chart) of the Text, the portion where the wind is strong corresponds to an area of such topography that there is a steep cliff on its windward side and the wind blows up, while the portion where the wind weakens corresponds to a flat and wide area in the airport.

In the vicinity of the runway threshold (Point R in Attached Fig. 2), CAS of HR-HOC suddenly decreased 12 kt in a second to 146 kt. The height at this time is about 40 ft. It would be at this location that the captain stated "After a call of the radio altimeter 60 ft, the aircraft suddenly made a rapid descent"

In the runway 16 wind sensor (see Attached Fig. 11 of the Text) is recorded a maximum of 310 deg/35 kt about 0511 UTC. From this record the duration of the peak can not be estimated, but in the 2-minute average wind sensor (see Note below) is recorded a maximum of 287 deg/27 kt (some error involved in reading of the wind speed) as an average vector for 3 seconds at almost the same time of period.

According to analysis results of DFDR and CVR, it is 0511:46 hours that the CAS suddenly decreased. If an eddy had moved with the average wind of 225 deg/15 kt, the aircraft, which was located about 350 meters leeward of the wind sensor when CAS suddenly changed, would have encountered the maximum of the wind direction and the wind speed with a delay of 350 m/15 kt=45 seconds, which shows a chronological coincidence.

It can not be decided from both records whether the appearing times of the maximum of the wind direction and the wind speed coincide with each other, or not. However, if the appearing times coincided and the aircraft encountered this wind at a height of about 40 ft, the aircraft would have been subjected to a tailwind with a maximum instantaneous speed of 32 kt judging from the record of the wind sensor, or a tailwind of 20 kt on a 3 second vector average from the record of the 2-minute wind sensor.

Meanwhile, the above figures seem excessive, since CAS of the aircraft increased about 8 kt in a second after an abrupt decrease of about 12 kt in a second. As the reason therefor, it is conceivable that (1) the appearing times of the maximum of the wind direction and the wind speed do not coincide, (2) the wind sensor is located distant from the position of the aircraft and therefore the wind at the wind sensor does not represent the situation of the wind at the location of the aircraft, and (3) the maximum of the 2-minute average wind speed can not be read out accurately, etc. However, since, as stated above, there exists the chronological coincidence, it is well conceivable that the aircraft encountered temporarily a strong tailwind.

It is not clear how the topography on the windward of the runway 16 wind sensor is related to generation of the eddy.

(Note): the 2-minute average wind sensor: Making, as pre-processing basic data, the average of the (12) values taken every 0.25 second for 3 seconds, and taking the moving average every 6 seconds as to

(40) values for 2 minutes, the average and the maximum in the 2 minutes are dotted. However, the maximum must be within the 2 minutes, and the time it appears is not recorded. The wind is calculated as a vector. As to the wind speed on the left side of Attached Fig. 12, the light brown indicates a maximum, and the blue an average, while as to the wind direction the green indicates a maximum, and the purple an average.

Addendum 1 Table 1

Comparison between Read-out from Wind Records of Runway 16 Anemometer and Wind Records of Aircraft

		Aircraft "A"	VR-HOC	Aircraft "B"
	Time Landed	04h45m01s(UTC)	05h11m49s(UTC)	05h18m48s(UTC)
Surface Observation	Northern Limit of Wind Direction (360°)	300° Instantaneously 320°	285° Instantaneously 310°	270° No Variation
	Variation Range of Wind Direction	300～200° * (Average 250°)	285～190° * (Average 238°)	270～180° * (Average 225°)
	Windspeed(Kt)			
	10-minute Average	12.0	15.0	15.0
	2-minute Average	12.0	15.0	15.0
	Record Paper	16.0	25.0	24.0
Aircraft Records	400～300ft (average wind Kt)	239(4)/33(8) N=9	No Record	215(6)/38(4) N=9
	200～20ft (average wind Kt)	239(15)/26(5) N=12		215(8)/30(8) N=13

Note (1) The figures marked with -- are indicated for reference purpose because they include a considerable reading error due to poor resolution of the record paper in terms of time.

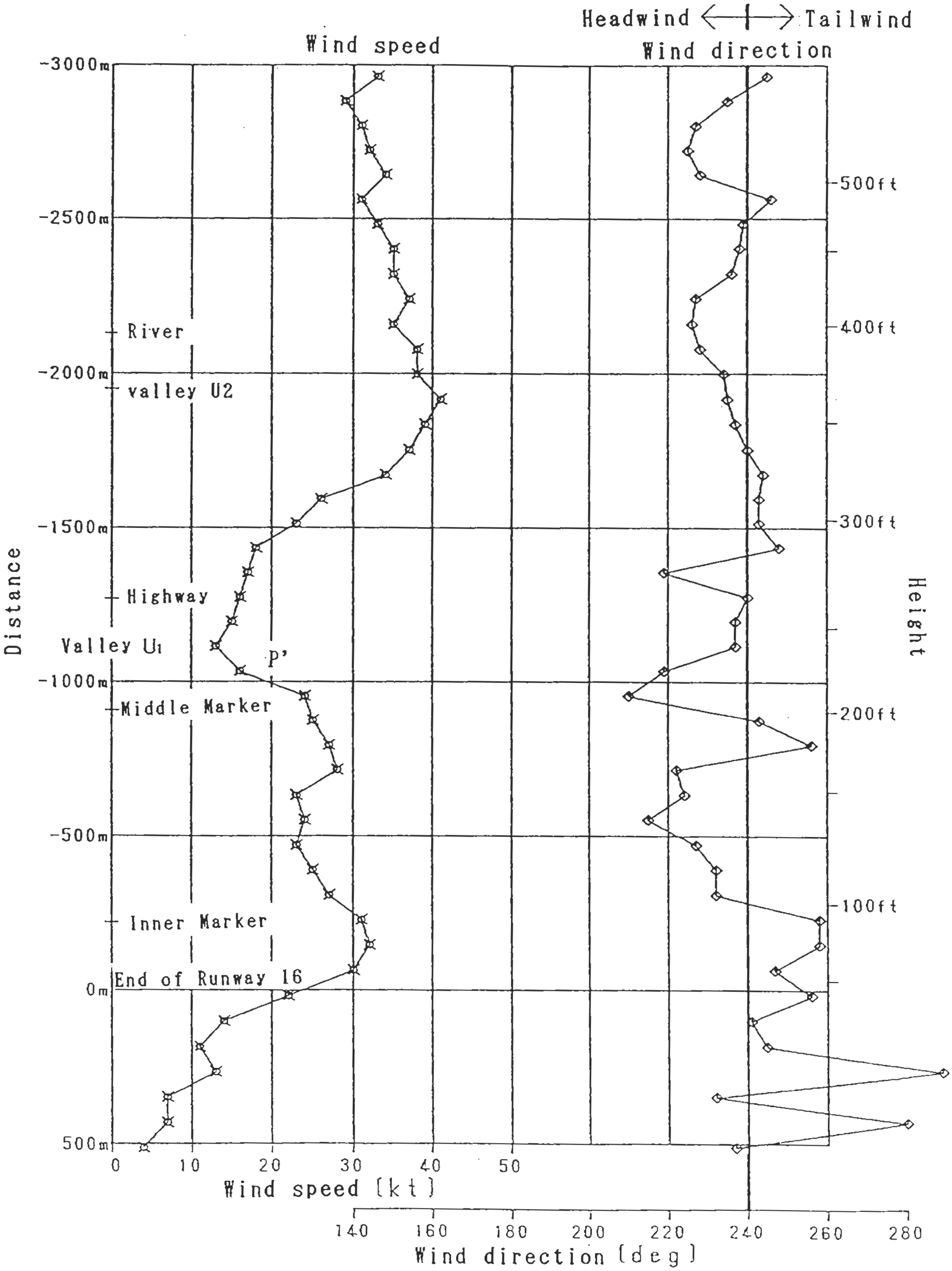
(2) The wind direction/speed of aircraft are values calculated as scalar, and the figures in parentheses indicate the number of dispersion, and N the number of data.

(3) Mark -- indicates read-out of the maximum wind speed for a period of an order of 5 minutes. They are for just for reference, because a considerable error may be expected.

(4) Time is in UTC.

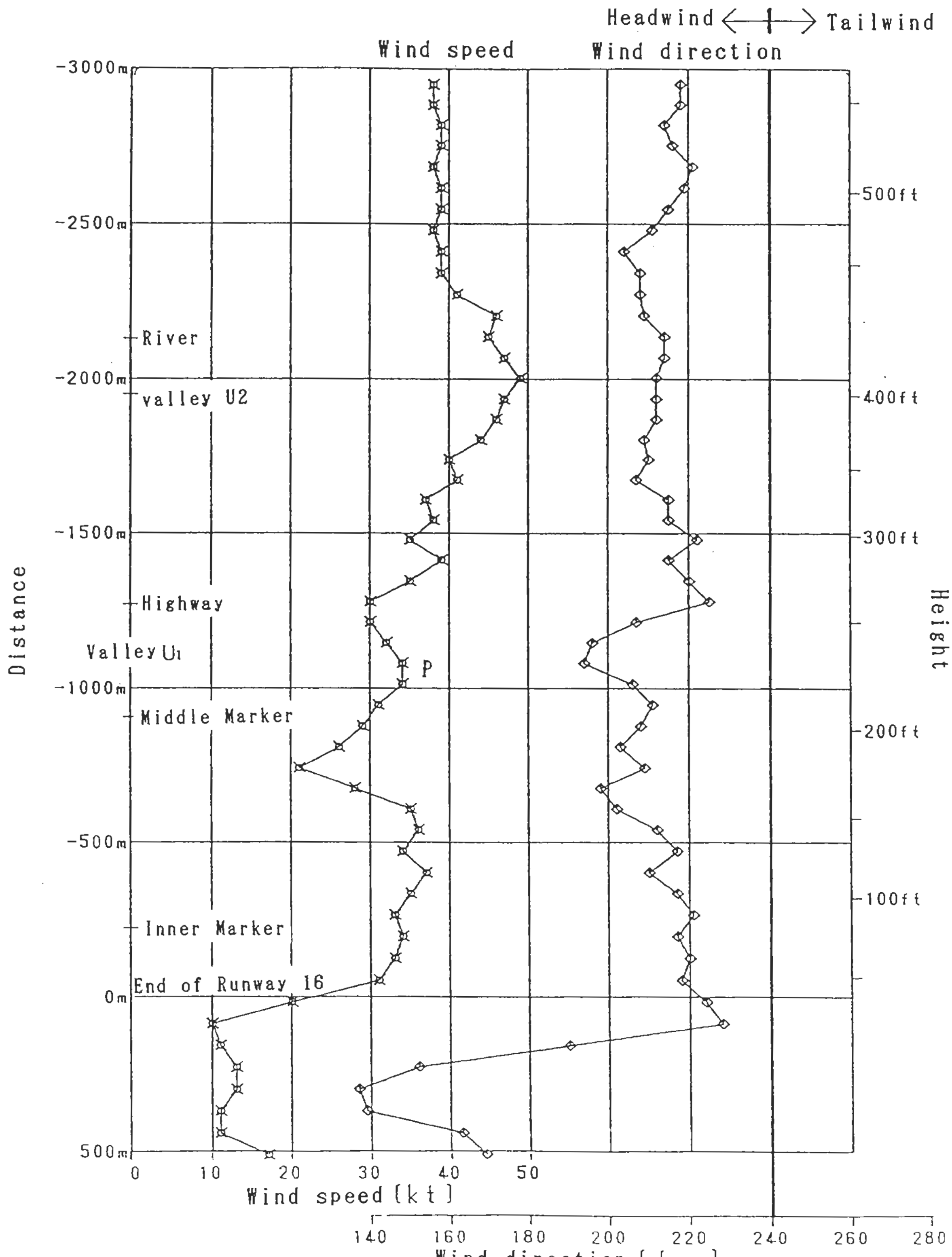
Addendum 1 Attached Fig.1a

Wind Records during approach and landing of Aircraft "A"



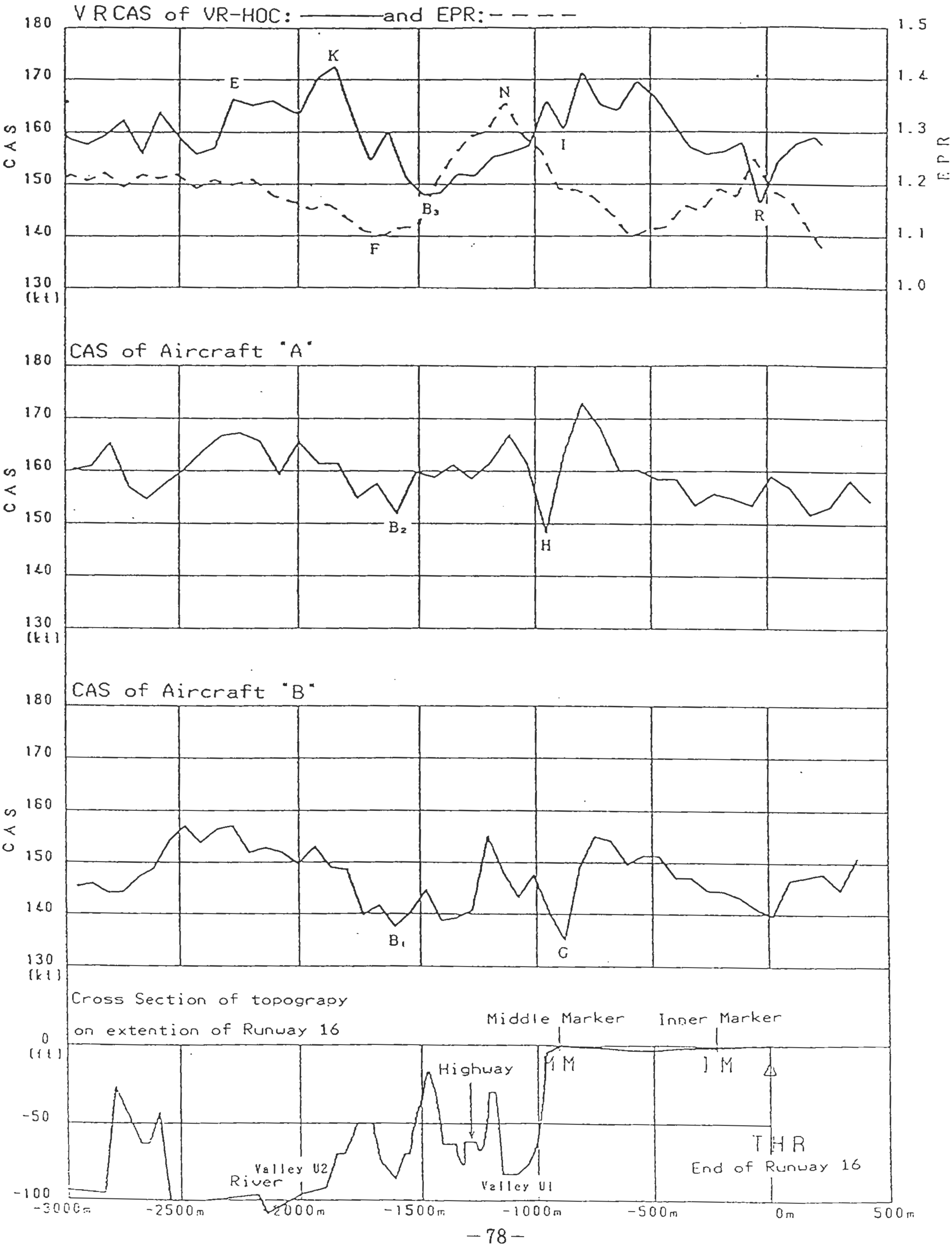
Addendum 1 Attached Fig.1b

Wind Records during approach and landing of Aircraft "B"



Addendum 1 Attached Fig. 2

Change in CAS during Approach and Landing



Addendum 2 Estimation of the wind from descent rate and motion of aircraft

1 Estimation of descent rate

The descent rate is estimated from records of the radio altitude and the vertical acceleration in DFDR by using the Karman Filter. The equation of motion is given as

$$\frac{\mathrm{d}h}{\mathrm{d}t} = -w$$

$$\frac{\mathrm{d}w}{\mathrm{d}t} = a_z$$

where h: height w: descent rate a_z: vertical acceleration

When the height recorded in DFDR is denoted as h^*, the vertical acceleration as a_z^*, measurement errors included in each of them as $\epsilon_h, \epsilon_{a_z}$,

$$h^* = h + \epsilon_h$$

$$a_z^* = a_z + \epsilon_{a_z}$$

The distribution of measurement errors was assumed as in the following. As to errors of the radio altimeter, two cases were taken into consideration, i.e., when on approach susceptible of influence of unevenness on the surface, a large error (30 ft) was anticipated, while when in the vicinity of the runway where the land is flat, an accuracy of 1 ft was expected.

$$E\left[\epsilon_{a_z}{}^2\right] = (0.05\mathrm{G})^2$$

$$E\left[\epsilon_h{}^2\right] = \begin{cases} (30\ \mathrm{ft})^2, & \text{if } h \geq 200\ \mathrm{ft}; \\ (1\ \mathrm{ft})^2, & \text{otherwise.} \end{cases}$$

The results are shown in Attached Fig. 1 of Addendum 2. The initial values used in this calculation are shown in the following table:

Assumption on initial values in estimation of descent rate

Time, t	about 7 seconds after landing (see Note)
Height, h	0
Descent Rate, w	0

(Note) Integrated in the reverse direction of the time axis

2 Estimation of wind from motion of aircraft

2.1 Estimation of wind in the heading

The wind speed in the heading was obtained from difference between the ground speed (calculated) and the airspeed (recorded in DFDR). The method to calculate the ground speed is as follows:

Firstly, we obtained the velocity (U) in the longitudinal direction, using the acceleration in the longitudinal direction (a_x) and the pitch attitude angle (Θ) recorded in DFDR, where the third and the fourth term on the right side of the motion equation

$$\dot{U} = a_x - g\sin\Theta - qW + rV$$

were omitted. Furthermore, the integral constant was determined by estimating an average ground speed from the middle marker to the inner marker based on the time required for passage of the distance.

Secondly, we obtained the ground speed in the runway direction by carrying out a coordinate conversion on the acquired speed along the aircraft axis, where $\Theta \simeq 0, \Phi \simeq 0, \Psi \simeq 0$ were assumed in the coordinate conversion equation

$$\begin{aligned}\dot{X}_{R/W} &= U\cos\Psi\cos\Theta \\ &\quad + V(\cos\Psi\sin\Theta\sin\Phi - \sin\Psi\cos\Phi) \\ &\quad + W(\cos\Psi\sin\Theta\cos\Phi + \sin\Psi\sin\Phi)\end{aligned}$$

$\dot{X}_{R/W}$:velocity component of X runway
U,V,W :velocity component of X body-axis
Φ,Θ,Ψ :roll angle, pitch attitude angle, yaw angle

The wind speed in the heading was calculated from the difference between the ground speed as acquired in the above and the airspeed recorded in DFDR.

2.2 Estimation of Crosswind

Since no data on the side slip angles are recorded in DFDR, it is impossible to estimate the crosswise wind by the same method as used in calculation of the longitudial wind in para. 2.1 above. Therefore, the crosswind in reference to the aircraft axis was estimated by reconstitution of the motion of the aircraft in the lateral direction, using the Karman Filter.

When the motion of aircraft is supposed to be linear and each measurement error is taken into consideration, the state equation and the measurement equation of the system are given respectively as follows:

$$
\begin{bmatrix} \dot{v} \\ \dot{p} \\ \dot{r} \\ \dot{\phi} \\ \dot{\psi} \\ \dot{v}_g \end{bmatrix}
=
\begin{bmatrix}
Y_\beta/V_{T_0} & Y_p + W_0 & Y_r - U_0 & g\cos\Theta_0 & 0 & Y_\beta/V_{T_0} \\
L'_\beta/V_{T_0} & L'_p & L'_r & 0 & 0 & L'_\beta/V_{T_0} \\
N'_\beta/V_{T_0} & N'_p & N'_r & 0 & 0 & N'_\beta/V_{T_0} \\
0 & 1 & \tan\Theta_0 & 0 & 0 & 0 \\
0 & 0 & \sec\Theta_0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}
\begin{bmatrix} v \\ p \\ r \\ \phi \\ \psi \\ v_g \end{bmatrix}
$$

$$
+ \begin{bmatrix}
Y_{\delta_a} & Y_{\delta_{sp}} & Y_{\delta_r} \\
L'_{\delta_a} & L'_{\delta_{sp}} & L'_{\delta_r} \\
N'_{\delta_a} & N'_{\delta_{sp}} & N'_{\delta_r} \\
0 & 0 & 0 \\
0 & 0 & 0 \\
0 & 0 & 0
\end{bmatrix}
\begin{bmatrix} \delta_a \\ \delta_{sp} \\ \delta_r \end{bmatrix}
+
\begin{bmatrix}
Y_{\delta_a} & Y_{\delta_{sp}} & Y_{\delta_r} & 0 \\
L'_{\delta_a} & L'_{\delta_{sp}} & L'_{\delta_r} & 0 \\
N'_{\delta_a} & N'_{\delta_{sp}} & N'_{\delta_r} & 0 \\
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
\begin{bmatrix} \epsilon_{\delta_a} \\ \epsilon_{\delta_{sp}} \\ \epsilon_{\delta_r} \\ \epsilon_{\dot{v}_g} \end{bmatrix}
$$

The aircraft characteristics (dimensioned derivatives) are based on data provided by the Lockheed Company.

The amounts to be measured are to be the roll angle (ϕ), yaw angle (ψ) and crosswise acceleration (a_y).

Since
$$\dot{v} = a_y + g\cos\Theta\sin\Phi + pW - rU$$

the measurement equation would be as follows:

$$
y = \begin{bmatrix} \phi \\ \psi \\ a_y + g\cos\Theta\sin\Phi \end{bmatrix}
= \begin{bmatrix}
0 & 0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 \\
Y_\beta/V_{T_0} & Y_p & Y_r & g\cos\Theta_0 & 0 & Y_\beta/V_{T_0}
\end{bmatrix}
\begin{bmatrix} v \\ p \\ r \\ \phi \\ \psi \\ v_g \end{bmatrix}
+ \begin{bmatrix} \epsilon_\phi \\ \epsilon_\psi \\ \epsilon_{a_y} \end{bmatrix}
$$

where all variables in a small letter in the expression above represent the disturbance from the initial value at the start of calculation.

v : disturbance of lateral speed
p, r : disturbance of roll rate, yaw rate
ϕ, ψ : disturbance of roll angle, yaw angle
v_g : disturbance of crosswind

In the calculation, initial values (approximately 30 seconds before touch-down) and measurement errors were assumed as follows:

Assumption on initial values

Flight Speed, V_{T_0}	160.0 kt
Speed in longitudinal direction of aircraft axis, U_0	158.1 kt
Speed in lateral direction of aircraft axis, V_0	0
Speed in vertical direction to aircraft axis, W_0	24.7 kt
Roll Angle, Φ_0	-2.8 deg
Pitch Angle, Θ_0	5.9 deg
Yaw Angle, Ψ_0	9.2 deg
Roll Rate, P_0	0
Yaw Rate, R_0	0
Crosswind to aircraft axis, V_{g_0}	0

Assumption on measurment errors

$$E[\epsilon_{\delta_a}{}^2] = (0.20 \text{ rad})^2$$
$$E[\epsilon_{\delta_{sp}}{}^2] = (0.10 \text{ rad})^2$$
$$E[\epsilon_{\delta_r}{}^2] = (0.20 \text{ rad})^2$$
$$E[\epsilon_{\dot{V}_g}{}^2] = (10 \text{ knot/s})^2$$
$$E[\epsilon_{\phi}{}^2] = (0.03 \text{ rad})^2$$
$$E[\epsilon_{\psi}{}^2] = (0.03 \text{ rad})^2$$
$$E[\epsilon_{a_y}{}^2] = (0.05 \text{ G})^2$$

Various values used in the calculation

Dimensions of aircraft

$$W = 357500 \text{ lb}$$
$$S = 3456 \text{ ft}^2$$
$$b = 155 \text{ ft}$$
$$\bar{c} = 24.46 \text{ ft}$$

Values given by Lockheed were used for I_X, I_Y, I_Z and I_{XZ}.

Flight Conditions

$$V = 160 \text{ knot}$$
$$\alpha = 8.86 \text{ deg}$$
$$\gamma = 3 \text{ deg}$$

Derivatives in the lateral direction

Values given by Lockheed were used.

2.3 Estimation of Wind direction and speed

From the wind speed in the heading U_g obtained in para. 2.1 and the crosswind to the aircraft axis V_g obtained in para. 2.2, we acquired the wind speed V_w and wind direction Ψ_w with reference to the coordinate system fixed on the earth surface.

$$V_{w,X} = U_g \cos\Psi_0 - V_g \sin(\Psi_0 + \psi)$$

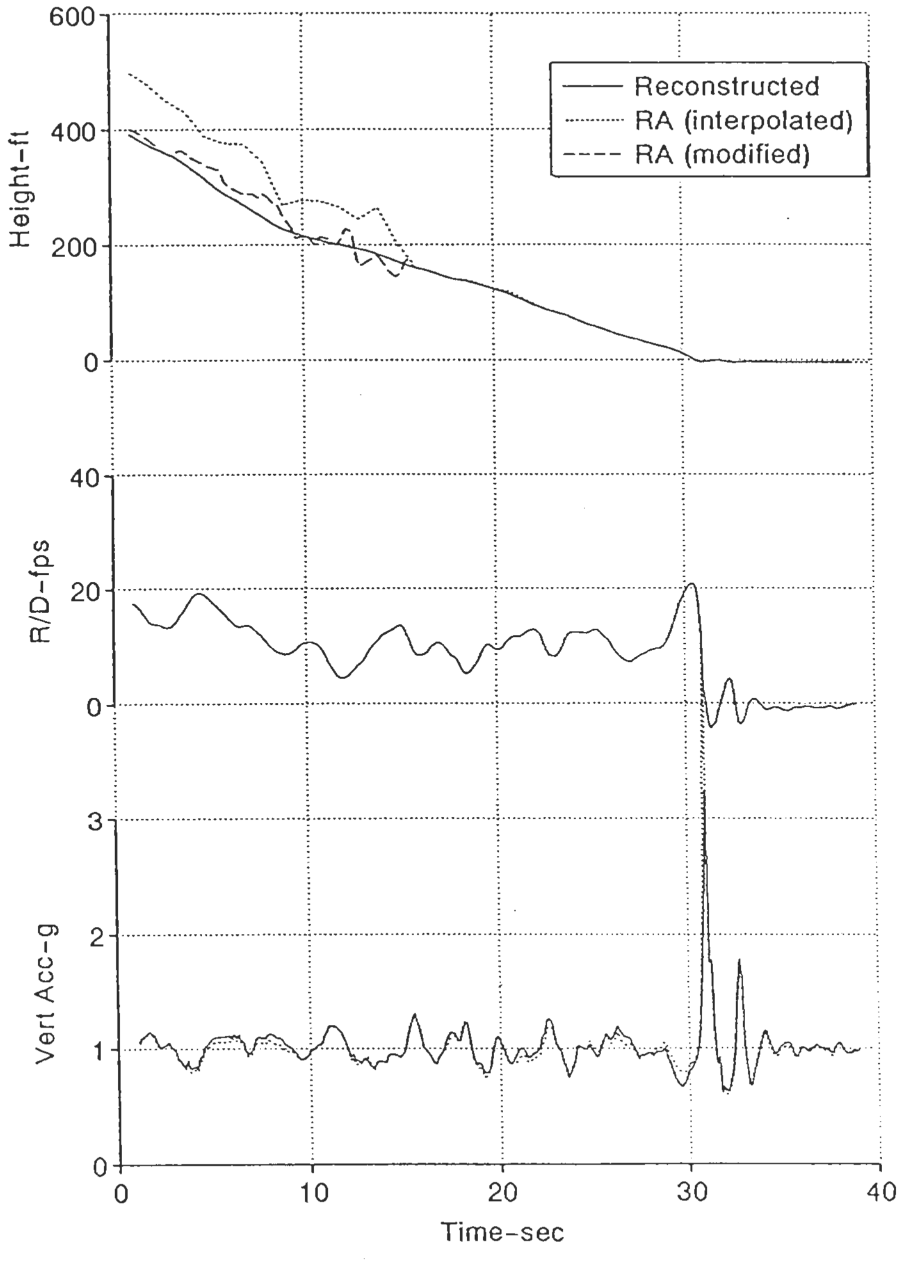
$$V_{w,Y} = U_g \sin\Psi_0 + V_g \cos(\Psi_0 + \psi)$$

$$V_w = \sqrt{(V_{w,X}^2 + V_{w,Y}^2)}$$

$$\Psi_w = \tan^{-1}(V_{w,Y}/V_{w,X})$$

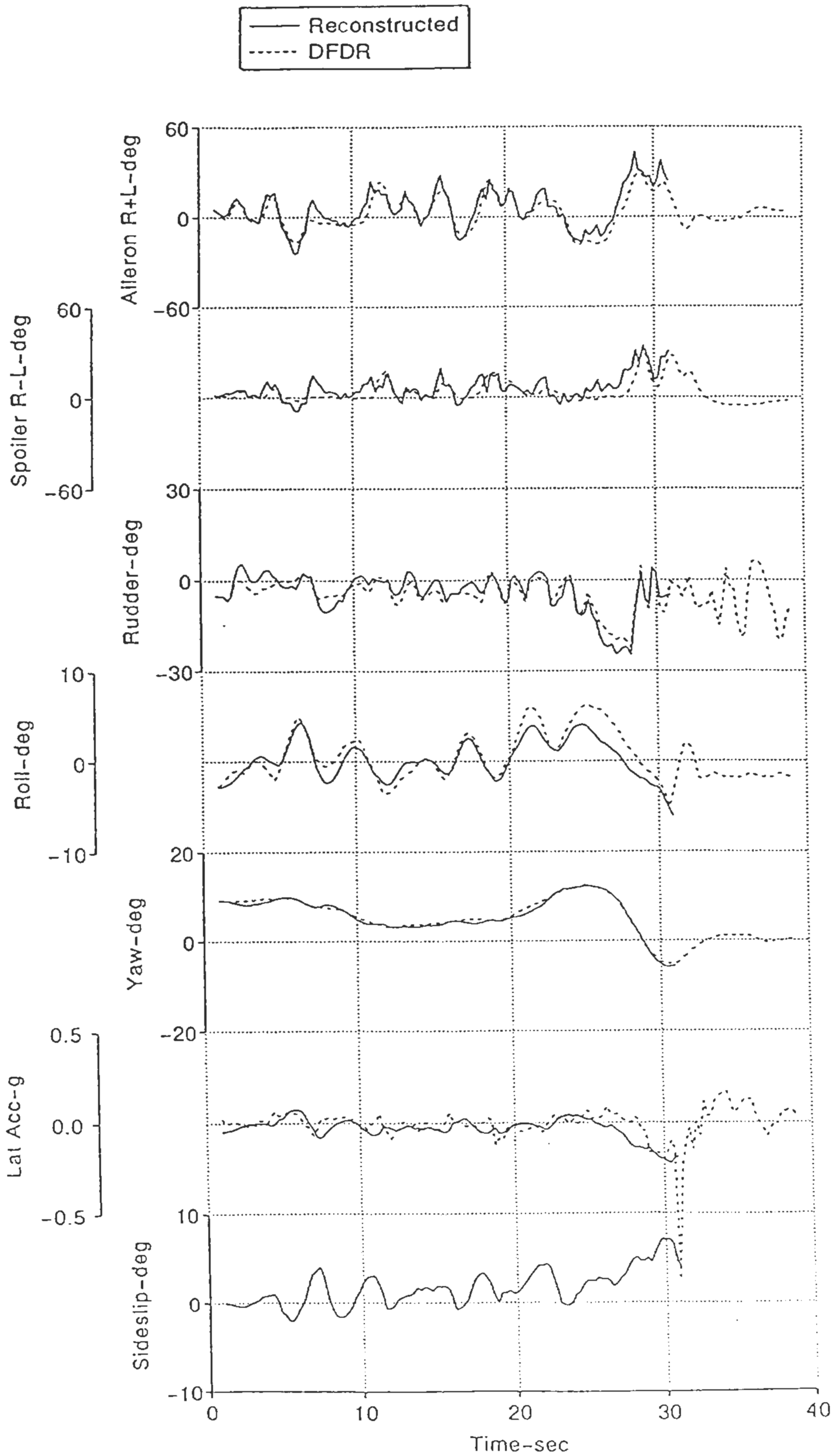
Addendum 2 Attached Fig. 1

Estimation of Descent Rate by Reconstruction of Height and Vertical Acceleration



Addendum 2 Attached Fig. 2

Estimation of Side Slip Angle by Reconstruction of Lateral Motion



Addendum 2 Attached Fig. 3

Estimation of Wind Direction and Speed

(taking the direction of Runway 16 as 0 degree)