AIRCRAFT ACCIDENT REPORT 1/95

ACCIDENTS INVESTIGATION DIVISION

Civil Aviation Department
Hong Kong

Report on the accident to
Boeing 747-409B B-165
at Hong Kong International Airport
on 4 November 1993

Hong Kong
August 1995

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August 1995

The Right Honourable Christopher Patten
Governor of Hong Kong
Government House
Hong Kong

Sir,

In accordance with regulation 10(6) of the Hong Kong Civil Aviation (Investigation of Accidents) Regulations I have the honour to submit the report by Mr. James C.S. HUI, an Inspector of Accidents, on the circumstances of the accident to Boeing 747-409B aircraft, Registration B-165, which occurred at Hong Kong International Airport on 4 November 1993.

Yours faithfully,

(P K N LOK)
Director of Civil Aviation

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GLOSSARY

Abbreviation	Explanation
AAIB	Air Accidents Investigation Branch (of the UK Department of Transport)
ACARS	Aircraft Communications Addressing and Reporting System
agl	Above ground level
AIP	Aeronautical Information Publication
ALTP	Airline Transport Pilot (Licence)
AMC	Air Movements Controller
AMO	Airport Meteorological Office
amsl	Above mean sea level
AOA	Angle Of Attack
APU	Auxiliary Power Unit
ASI	Air Speed Indicator
ATC	Air Traffic Control
ATIS	Automatic Terminal Information Service
CAD	Civil Aviation Department
CAS	Calibrated Airspeed
CCTV	Closed Circuit Television
CAL	China Airlines
CMC	Central Maintenance Computer
CRM	Cockpit Resource Management
CVR	Cockpit Voice Recorder
DFDR	Digital Flight Data Recorder
DME	Distance Measuring Equipment
EADI	Electronic Attitude and Direction Indicator
EEC	Electronic Engine Control
EEPROM	Electrically Erasable Programmable Read Only Memory
EGT	Exhaust Gas Temperature
EICAS	Engine Indicating and Crew Alerting System
EPR	Engine Pressure Ratio
FCTM	Flight Crew Training Manual
FMC	Flight Management Computer
fpm	Feet per minute
g	acceleration of gravity
GND	Ground
GPWC	Ground Proximity Warning Computer
GPWS	Ground Proximity Warning System
HAECO	Hong Kong Aircraft Engineering Company Ltd.
HKIA	Hong Kong International Airport
hPa	Hectopascal(s)
hr	Hour(s)

ICAO	International Civil Aviation Organisation
IGS	Instrument Guidance System
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
INS	Inertial Navigation System
IRU	Inertial Reference Unit
kt	knots (nautical miles per hour)
MEC	Main Engine Control
MK	Mark
mm	Millimetre
N1	Engine fan speed
N2	Engine core speed
ND	Navigation Display
NM	Nautical Mile(s)
NTSB	National Transportation Safety Board (of the USA)
NVM	Non-Volatile Memory
PA	Passenger Address
PAPIs	Precision Approach Path Indicators
PFD	Primary Flight Display
PIC	Pilot In Command (Commander)
PNF	Pilot Not Flying
PSEU	Proximity Sensor Electronic Unit
psi	Pounds per square inch
QAR	Quick Access Recorder
QNH	Pressure setting at which a barometric altimeter reads airport elevation when on the ground at that airport
QRH	Quick Reference Handbook
RMS	Root Mean Square
RTF	Radio Telephony
RVR	Runway Visual Range
RWY	Runway
SIGMET	Significant Meteorological (Warning)
SOP(s)	Standard Operating Procedure(s)
TAF	Terminal Area Forecast
TLA	Thrust Lever Angle
TOGA	Take-off/Go-Around
u/s	Unserviceable
UTC	Co-ordinated Universal Time
VHF	Very High Frequency
VOR	VHF Omni-Range (A beacon which provides magnetic bearing)
V_R	Rotation speed on take-off
V_{REF}	Minimum speed at 50 foot height in a normal landing
V_2	Take-off safety speed
YYC	Yau Yat Chuen (an anemometer location beneath the IGS approach)

ACCIDENT INVESTIGATION DIVISION

CIVIL AVIATION DEPARTMENT

Aircraft Accident Report No 1/95

Owner and operator:	China Airlines
Aircraft Type:	Boeing 747-409B
Nationality:	Taiwan
Registration:	B-165
Place of Accident:	Hong Kong International Airport
Date and time:	4 November 1993 at 0336 hr (1136 hr local time)

All times in this report are UTC

SYNOPSIS

On the day of the accident, Hong Kong International Airport (HKIA) was affected by a tropical cyclone centred some 300 kilometres south-southwest of Hong Kong. There was a strong gusty wind from the east. It was raining and the runway was wet. The aircraft carried out an Instrument Guidance System (IGS) approach to runway 13. As it commenced the visual right hand turn onto short final it encountered windshear characterised by a sustained reduction in airspeed and an abnormally high sink rate. The commander continued the approach and landed slightly faster than he had intended but within the normal touchdown zone. Soon after touchdown a period of undesired wing rocking commenced and selection of reverse thrust was postponed until roll control was regained. Heavy wheel braking and reverse thrust were then applied but the retardation was insufficient to stop the aircraft within the remaining runway distance. A turn to the left was initiated shortly before the aircraft ran off the runway at an angle to the left of the centreline at a ground speed of 30 kt. The nose and right wing dropped as it departed the runway promontory and it entered the sea creating a very

large splash which was observed from the control tower, some 3.5 km to the northwest. The Air Movements Controller (AMC) immediately activated the crash alarm and the Airport Fire Contingent responded very rapidly in their fire appliances and fire boats. Other vessels in the vicinity also provided prompt assistance.

On impact with the sea significant structural damage was incurred by the engines on the right wing, one of which separated, and by the nose section surrounding the lower passenger cabin. The aircraft remained afloat and drifted back towards the runway. Evacuation started shortly after the aircraft came to rest and all 296 persons on board were rescued. Of the 10 injured, only one person was categorized as 'serious' per ICAO definition, having been hospitalised for more than 48 hours. (He was discharged 5 days later.) The aircraft was salvaged from the sea some two weeks after the accident but it was beyond economic repair.

The investigation team identified the following major causal factors :

(i) The commander deviated from the normal landing roll procedure in that he inadvertently advanced the thrust levers when he should have selected reverse thrust.

(ii) The commander diminished the co-pilot's ability to monitor rollout progress and proper autobrake operation by instructing him to perform a non-standard duty and by keeping him ill-informed about his own intentions.

(iii) The co-pilot lacked the necessary skill and experience to control the aircraft during the landing rollout in strong, gusty crosswind conditions.

(iv) The absence of a clearly defined crosswind landing technique in China Airline's Operations Manual deprived the pilots of adequate guidance on operations in difficult weather conditions.

During the course of the investigation, 18 safety recommendations were made. These are summarised at pages 120-122.

1. FACTUAL INFORMATION

1.1 History of the flight

China Airlines' scheduled passenger flight CAL605 departed Taipei at 0220 hr for the 75 minute flight to Hong Kong. The departure and cruise phases were uneventful. During the cruise the commander briefed the co-pilot on the approach to Hong Kong International Airport (HKIA) using the airline's own approach briefing proforma as a checklist for the topics to cover. The briefing included the runway-in-use, navigation aids, decision height, crosswind limit and missed approach procedure. He paid particular attention to the crosswind and stated that, should they encounter any problem during the approach, they would go-around and execute the standard missed approach procedure. The commander did not discuss with the co-pilot the autobrake setting, the reverse thrust power setting or their actions in the event of a windshear warning from the Ground Proximity Warning System (GPWS).

At 0228 hr the co-pilot obtained the 0200 hr weather report for HKIA using the Aircraft Communications Addressing and Reporting System (ACARS) which received text by VHF radio data link and printed it on paper. He handed the printed report to the commander for him to read. Later, before commencing descent, both pilots listened to a voice report of the 0235 hr weather observation broadcast by the Hong Kong Automatic Terminal Information Service (ATIS). Both observations reported strong gusty wind conditions, rain and windshear. The ACARS report contained data relating to variable wind directions and the ATIS reported moderate to severe turbulence on the approach. During the early stages of the descent the commander identified returns on the aircraft's weather radar which were consistent with cumulo-nimbus clouds over the sea to the south-west of Hong Kong but saw none in the vicinity of the airport.

On establishing radio contact with Hong Kong Approach Control at 0317 hr, the crew were informed that ATIS information 'GOLF' was current and were given radar control service to intercept the IGS approach to runway 13 which is offset from the extended runway centreline by 47° (see instrument approach chart at Appendix 1). After intercepting the IGS localiser beam, the pilots changed frequency to Hong Kong Tower and were informed by the AMC that the visibility had decreased to 5 kilometres in rain and the mean wind speed had increased to 22 kt. The aircraft ahead of them on the approach was given touchdown winds of 060°/28 kt and 060°/25 kt. This preceding aircraft, an MD 82, landed successfully. Two minutes before clearing CAL605 to land, the AMC advised the crew that the wind was 070°/25 kt and to expect windshear turning short final.

During the approach the pilots completed the landing checklist for a flaps 30 landing with the autobrakes controller selected to position '2' and the spoilers armed. The reference airspeed (V_{REF}) at the landing weight was 141 kt; to that speed the commander added half the reported surface wind to give a target airspeed for the final approach of 153 kt.

Rain and significant turbulence were encountered on the IGS approach and both pilots activated their windscreen wipers. At 1,500 feet altitude the commander noted that the wind speed computed by the Flight Management Computer (FMC) was about 50 kt. At 1,100 feet he disconnected the autopilots and commenced manual control of the flightpath. A few seconds later at 1,000 feet he disconnected the autothrottle system because he was dissatisfied with its speed holding performance. From that time onwards he controlled the thrust levers with his right hand and the control wheel with his left hand. Shortly afterwards the commander had difficulty in reading the reference airspeed on his electronic Primary Flying Display (PFD) because of an obscure anomaly, but this was rectified by the co-pilot who re-entered the reference airspeed of 141 kt into the FMC.

Shortly before the aircraft started the visual right turn onto short final, the commander saw an amber 'WINDSHEAR' warning on his PFD. A few seconds later, just after the start of the finals turn, the ground proximity warning system (GPWS) gave an aural warning of "GLIDESLOPE" which would normally indicate that the aircraft was significantly below the IGS glidepath. One second later the aural warning changed to "WINDSHEAR" and the word was repeated twice. At the same time both pilots saw the word 'WINDSHEAR' displayed in red letters on their PFDs. Abeam the Checkerboard the commander was aware of uncommanded yawing and pitch oscillations. He continued the finals turn without speaking whilst the co-pilot called deviations from the target airspeed in terms of plus and minus figures related to 153 kt. At the conclusion of the turn both pilots were aware that the aircraft had descended below the optimum flight path indicated by the optical Precision Approach Path Indicator (PAPI) system.

The AMC watched the final approach and landing of the aircraft. It appeared to be on or close to the normal glidepath as it passed abeam the tower and then touched down gently on the runway just beyond the fixed distance marks (which were 300 metres beyond the threshold) but within the normal touchdown zone. The AMC was unable to see the aircraft in detail after touchdown because of water spray thrown up by it but he watched its progress on the Surface Movement Radar and noted that it was fast as it passed the penultimate exit at A11. At that time he also observed a marked increase in the spray of water from the aircraft and it began to decelerate more effectively.

The commander stated that the touchdown was gentle and in a near wings-level attitude. Neither pilot checked that the speed brake lever, which was 'ARMED' during the approach, had moved to the 'UP' position on touchdown. A few seconds after touchdown, when the nose wheel had been lowered onto the runway, the co-pilot took hold of the control column with both hands in order to apply roll control to oppose the crosswind from the left. The aircraft then began an undesired roll to the left. Immediately the commander instructed the co-pilot to reduce the amount of applied into-wind roll control. At the same time he physically assisted the co-pilot to correct the aircraft's roll attitude. Shortly after successful corrective action the aircraft again rolled to the left and the commander intervened once more by reducing the amount of left roll control wheel rotation. During the period of unwanted rolling, which lasted about seven seconds, the aircraft remained on the runway with at least the left body and wing landing gears in contact with the surface. After satisfactory aerodynamic control was regained, the co-pilot noticed a message on the Engine Indicating and Crew Alerting System (EICAS) display showing that the autobrake system had disarmed. He informed the commander that they had lost autobrakes and then reminded him that reverse thrust was not selected. At almost the same moment the commander selected reverse thrust on all engines and applied firm wheel braking using his foot pedals. As the aircraft passed abeam the high speed exit taxiway (A11), the commander saw the end of the runway approaching. At that point both he and the co-pilot perceived that the distance remaining in which to stop the aircraft might be insufficient. At about the same time the co-pilot also began to press hard on his foot pedals. As the aircraft approached the end of the paved surface the commander turned the aircraft to the left using both rudder pedal and nose wheel steering tiller inputs. The aircraft ran off the end of the runway to the left of the centreline. The nose and right wing dropped over the sea wall and the aircraft entered the sea creating a very large plume of water which was observed from the control tower, some 3.5 km to the northwest. The AMC immediately activated the crash alarm and the Airport Fire Contingent, which had been on standby because of the strong winds, responded very rapidly in their fire vehicles and fire boats. Other vessels in the vicinity also provided prompt assistance.

After the aircraft had settled in the water, the commander operated the engine fuel cut-off switches and the co-pilot operated all the fire handles. The commander attempted to speak to the cabin crew using the interphone system but it was not working. The senior cabin crew member arrived on the flight deck as the commander was leaving his seat to proceed aft. The instruction to initiate evacuation through the main deck doors was then issued by the commander and supervised by the senior cabin crew member from the main deck.

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	-	-	-
Serious	-	1	-
Minor	-	9	-
None	22	264	

1.3 Damage to aircraft

The aircraft sustained physical damage to its fuselage, nose gear structure, flaps, engines and some control surfaces, but otherwise remained largely intact. Both engines on the right wing detached but the wing and horizontal stabiliser structural boxes remained intact and the aircraft floated.

1.4 Other damage

There was minor damage to the innermost lighting structures off the end of the runway and the edge of the sea wall suffered slight abrasion from contact with the aircraft. Water pollution was largely avoided as little if any fuel was spilt.

1.5 Personnel information

1.5.1 Flight crew qualifications

Commander	:	Male, aged 47 years
Licence	:	Airline Transport Pilot's Licence
Type ratings	:	Boeing 747-400 series
Instrument rating	:	Instrument rating renewed 28 Aug 93
Medical certificate	:	Valid with requirement to wear glasses
Last base check	:	15 July 93
Last route check:	:	10 Jun 93
Last emergency drills check	:	3 Jun 93
Flying experience		
Total all types	:	12,469 hr
Total on type	:	3,559 hr
Total last 30 days	:	85 hr
Duty time		
On day of the accident	:	3 hr 52 min
On day before the accident	:	No duties

Co-pilot	:	Male, aged 37 years
Licence	:	Senior Commercial Pilot's Licence
Type ratings	:	Boeing 747-400 series
Instrument rating	:	Instrument rating renewed 7 Sep 93
Medical certificate	:	Valid with no limitations
Last base check	:	7 Sep 93
Last route check:	:	17 Jul 93
Last emergency drills check	:	9 Oct 93

Flying experience

Total all types	:	5,705 hr
Total on type	:	908 hr
Total last 30 days	:	70 hr
Duty time		
On day of the accident	:	3 hr 52 min
On day before the accident	:	No duties

1.5.2 Flight crew histories

The commander joined China Airlines in 1984 after flying 2800 hr on F104 Starfighter aircraft with the Air Force of Taiwan. His civil flying career began as a co-pilot on Boeing 707 and he transferred to the Boeing 767 in late 1984. In 1986 he was promoted to Captain on the Boeing 767. He transferred to the Boeing 747-200 in late 1988 and flew the type for 1,270 hr. In March 1990 he became one of China Airlines' first Boeing 747-400 commanders. Approximately two months before the accident he became a training captain on that type.

The co-pilot served as a light aircraft pilot with the Army of Taiwan. On leaving the Army he flew as co-pilot on Dornier Type and SAAB 340 turboprop transport aircraft with a regional airline. He joined China Airlines in July 1992 and, after conversion training, was appointed as first officer on the Boeing 747-400.

Both pilots had operated the 747-400 to Hong Kong several times before; their frequency of operation to HKIA was approximately once or twice a month. Both had attended a Cockpit Resource Management course run by China Airlines, the commander in 1993 and the co-pilot in 1992.

1.5.3 **Flight crew training**

Because the commander had significant experience of flying the Boeing 747-200, before flying the 747-400 he was given a 'differences' conversion course. The conversion training was conducted in Taiwan early in 1990 by instructors from the Boeing Airplane Company which supplied copies of the syllabus and training records to the investigation team. The course included 83 hr of classroom tuition, 18 hr of flying in a full flight simulator and 1.5 hr flight in an aircraft. The syllabus included instruction in autobrake management, windshear encounter during the approach, crosswind landing technique and rejected landing technique. These topics were taught in a manner consistent with the practices described in Boeing's Flight Crew Training Manual (FCTM). The commander's training records revealed that during the course he performed well. During interview the commander stated that he had last practised windshear recovery procedures in the China Airlines' flight simulator between four and six months before the accident. The co-pilot was trained to fly the B747-400 by China Airlines' staff at Taipei. Lacking any previous experience of handling Boeing airliners, he was given a full conversion course. There were two recorded instances (Exercises 1 and 4 of the simulator phase) where he was criticised for jerky or excessive application of aileron. At interview, the co-pilot stated that he had practised windshear recovery procedures in a flight simulator some six months before the accident. The training involved simulation of windshear and windshear warnings from the GPWS.

1.5.4 Flight attendants

There were 20 flight attendants each of whom met China Airline's requirements. They received annual recurrent training and evaluation in emergency and evacuation procedures. Each flight attendant had completed the training during June or July 1993.

1.6 Aircraft information

1.6.1 Aircraft particulars

Model No	:	Boeing 747-409B, Serial No 24313
Manufacturer	:	Boeing Commercial Aircraft Group, Seattle, USA
Registered Owner	:	Civil Aeronautics Administration, Taiwan
Registration No	:	B - 165
Operator	:	China Airlines
Date of Manufacture	:	8 June 1993
Engines	:	Four Pratt and Whitney PW4056 turbofans
Maximum landing weight	:	630,000 lb (286.4 tonnes)
Estimated landing weight	:	525,718 lb (239.0 tonnes)
Zero fuel weight	:	476,116 lb (216.4 tonnes)
Zero fuel centre of gravity	:	27.1% mean aerodynamic chord
Certificate of Airworthiness	:	No. 85-05-37, valid from 9 June 1993 to 31 May 1994
Certificate of Registration	:	No. 82-519 issued 8 June 1993
Total Flying Time	:	1969:34 hr
Total Cycles	:	359

Maintenance History : The aircraft entered service in June 1993 and five scheduled 'A' checks had been carried out, as follows:-

Check	Date	Hours
1A	3.7.93	290:1
2A	2.8.93	696:52
3A	30.8.93	1078:02
4A	19.9.93	1341:35
5A	16.10.93	1711:30

The next scheduled check would have been due at 2111:30 hr.

1.6.2 Engine Indicating and Crew Alerting System (EICAS)

The EICAS is the only means of displaying engine indications, and is the primary means of displaying aeroplane system indications and alerts to the flight crew. The most important indications appear on the primary EICAS display, which is normally displayed on the upper central cathode ray tube (CRT); the secondary EICAS display normally appears on the lower CRT (see Appendix 2). System conditions and configuration information is provided to the crew by EICAS alert, memo, and status messages.

Alert messages are the primary method of alerting the crew to abnormal conditions. They are subdivided into three categories: the highest priority are warning messages which appear in red; next in priority are caution messages which appear in amber; and third in priority are advisory messages which also appear in amber.

Memo messages are reminders to the crew of the current state of certain selected normal conditions. They appear in white on the primary EICAS display. Status messages indicate equipment faults which may affect aeroplane dispatch capability. Like memo messages they are displayed in white but appear on the secondary EICAS display.

Aural alerts are used to call attention to EICAS warning and caution messages; these are also accompanied by master warning lights. There is no aural or master warning light accompaniment to EICAS advisory, memo or status messages.

1.6.3 Speedbrakes

The function of the speedbrake system is to increase drag and reduce lift both in the air and on the ground. The system consists of 12 spoiler panels, numbered 1 to 12 from left to right along the aft section of the wings. The five outermost spoilers on each wing act as flight spoilers, the innermost one acts only as a ground spoiler (see Appendix 3). On the ground all surfaces respond to speedbrake lever commands whether in manual or automatic mode. With the speedbrake lever in the 'ARMED' position, the system provides automatic extension of all flight and ground spoilers at touchdown or during a rejected take off. The position of the lever provides a visual indication of speedbrake status and the motor operation can be heard on the flight deck. The flight and ground spoilers will automatically retract when a go-around is initiated by forward movement of the thrust levers after touchdown. There is no EICAS message or audio warning which accompanies automatic retraction of the speedbrakes.

The speedbrake lever is located on the forward left side of the control pedestal. The system incorporates an electrical actuator for automatic operation on the ground and a solenoid operated flight stop to prevent ground spoiler deployment in flight. A spring inside the speedbrake lever holds it in a detent in the down position when fully forward (spoilers retracted). Lifting the lever out and moving it approximately 3° aft arms the system ready for automatic deployment when the correct conditions are met on landing (see Appendix 3).

1.6.4 Wheel brakes

The wheel braking system on this aircraft incorporates full anti-skid, locked wheel touchdown and hydroplaning (aquaplaning) protection, plus brake torque limiters. The wheel brakes can be controlled by either pilot using foot pedals or automatically by the autobrake system. With manual braking, any level up to maximum may be selected at the pilot's discretion depending on how far the rudder pedals are rocked forward. When armed, the autobrake system will apply hydraulic pressure to the brake packs upon main gear touchdown (sensed by main wheel spin-up and main gear on ground), in order to achieve a pre-set rate of deceleration. It is a condition for autobrake operation that all four thrust levers are within the idle range within 3 seconds after touchdown. If not, the autobrake selector knob will rotate to the 'DISARM' position, the autobrakes will be deactivated and a thrust lever fault will be stored in the CMC. The change in autobrake status is indicated by a change from the white memo message 'AUTOBRAKES 2' to the amber advisory message of 'AUTOBRAKES'; there is no audio warning which accompanies the change in status.

1.6.5 Thrust control

The thrust levers signal the electronic engine control units (EECs) by electrical means, not mechanical cables. Thrust lever angle is sensed by a resolver, one linked to each lever, mounted beneath the pedestal. The thrust lever assembly includes forward and reverse thrust levers mounted on the control stand (Appendix 4). On the assembly are pilot controlled switches for autothrottle disengagement and the Take-Off/Go-Around (TOGA) functions. The thrust levers can rotate forwards through 50 degrees from the idle position to the full forward thrust position; the reverse thrust levers rotate backwards through 89.25 degrees. Interlocks mechanically prevent simultaneous movement of the forward and reverse thrust levers. Reverse thrust cannot be selected unless the forward thrust levers are at idle and the air/ground logic senses that the aircraft is on the ground.

Raising the reverse thrust levers to the idle detent locks the forward thrust levers at idle. Hydraulic pressure then unlocks and extends the fan air thrust reversers to the deployed position. A thrust reverser status annunciator is displayed above the digital indicator of each Engine Pressure Ratio (EPR) indication. The annunciator changes colour from amber to green when the reverser is fully deployed and the reverse thrust levers can then be moved to full reverse.

The engines have two idle settings: flight idle and ground idle. Flight idle speed is slightly faster than ground idle speed. The change from flight idle to ground idle is not a function of thrust lever angle; it is an automated function of the EECs which occurs 5 seconds after touchdown if the thrust levers are in the idle range. Typically the engines take 6 to 10 seconds to accelerate from minimum idle to maximum reverse once reverse thrust is selected.

1.6.6 Ground Proximity Warning System

The aircraft was fitted with a Sundstrand Mk V GPWS. In flight, this provides windshear warnings and alerts under the following conditions:

(i) Below 1,500 feet agl during the initial take-off and final approach phases of flight when the level of windshear exceeds predetermined threshold values. The actual windshear value which is measured represents the vector sum of air mass accelerations along the flight path and perpendicular to the flight path. These shears result from vertical winds and rapidly changing horizontal winds.

(ii) PFD amber 'WINDSHEAR' annunciations are given for increasing head wind (or decreasing tail wind) and vertical up drafts typically associated with the leading edge of microburst windshears.

(iii) PFD red 'WINDSHEAR' annunciations are given for decreasing head wind (or increasing tail wind) and severe vertical down drafts.

1.6.7 Rain clearance

Both pilots' windshields were equipped with independently controlled, two speed windshield wipers. Each windshield was also equipped with a rain repellent system to augment the windshield wipers.

1.7 Meteorological information

1.7.1 Airport meteorological office

Forecasts and observations issued by the Airport Meteorological Office (AMO) at HKIA were disseminated in real time by video monitor, by point-to-point dedicated circuits and by scheduled broadcasts, with additional meteorological information available on request. Routine, special and extra meteorological reports, trend-type landing forecasts, aerodrome forecasts, SIGMET information, current RVRs, aerodrome warnings and other relevant supplementary information are provided to air traffic services units. Meteorological information transmitted by closed circuit television (CCTV) to displays at the various ATC positions comprises half-hourly reports, special reports, aerodrome forecasts, surface wind information and windshear warnings for HKIA.

1.7.2 General weather situation

A tropical cyclone bulletin issued by the Royal Observatory at 0245 hr on 4 November stated that the Strong Wind Signal Number 3 was still hoisted. This signal conveys a general expectation of strong winds with sustained speeds between 22 and 33 kt and the possibility of gusts giving peak winds which may exceed 60 kt. At 0300 hr the centre of severe tropical storm Ira was estimated to be near position 20° N, 112.7° E (approximately 160 NM SSW of HKIA). The centre of the storm was moving north-west at a speed of about 9 kt.

A pictorial routine aviation forecast of significant weather above 25,000 feet for south-east Asia prepared in Tokyo, which was carried on board the aircraft, forecast an area of thunderstorm and cumulonimbus clouds associated with cyclone Ira which, at its periphery, would cover Hong Kong at 0330 hr on 4 November. The tops of the cumulo-nimbus clouds were likely to extend to an altitude of 55,000 feet. The low altitude aviation weather forecast prepared in Hong Kong for the 50 NM radius around the airport warned of strong gusty easterly winds during the afternoon (local time) moderating gradually by evening. The general weather would be overcast with rain and occasional squalls. The winds at altitude would be around 35 kt with gusts to 65 kt at 2,000 feet, and 55 kt at 5,000 feet. Moderate to severe turbulence was forecast.

1.7.3 Weather forecasts for Hong Kong International Airport

Before leaving Taipei, both pilots knew that weather conditions at Hong Kong were being influenced by a tropical cyclone. They had with them a folder containing a satellite photograph of the cloud affecting southern China and the South China Sea, meteorological charts, terminal approach forecasts and recent weather reports. The most recent Terminal Aerodrome Forecast (TAF) for HKIA given to the crew before departure from Taipei was issued at midnight (UTC) on 3 November. The forecast, which was valid for the 24 hr of 4 November may be summarised as follows:

Wind 070°/18 kt gusting to 40 kt; visibility 8,000 metres in rain, scattered cloud base at 1,600 feet, scattered cloud base at 2,000 feet and broken cloud base at 8,000 feet. During the period from 0000 to 0600 hr, the wind was forecast to change temporarily to 090°/28 kt with gusts to 50 kt; visibility would reduce temporarily to 3,000 metres in rain showers and the base of the lowest cloud would reduce temporarily to 1,000 feet.

Elements of the forecast, including the maximum wind speeds and the temporary reduction of visibility to 3,000 metres had been underlined in red with a felt tip pen. Routine updates to the weather forecast for HKIA were issued by the AMO at 0030 and 0237 hr. These were not available to the flight crew because of transmission and flight preparation time scales. However, there were no changes which would have had a significant effect on flight operations.

1.7.4 Actual weather conditions at Hong Kong International Airport

Before departure from Taipei the flight crew were in possession of the five most recent weather observations for HKIA that were available at the time; the reports were timed at hourly intervals between 03 2000 hr and 04 0000 hr. All five observations contained references to windshear on the approach to runway 13/31, winds from 070° with mean strengths of 17 kt or more, gusts above 30 kt and trends of no significant change. From 03 2100 hr onwards, all the observations reported rain at the airport. The observation reports issued by the AMO for the period 04 0000 hr to 04 0400 hr are summarised in this report at Appendix 5.

1.7.5 Automatic Terminal Information Service (ATIS)

Shortly before commencing descent the flight crew listened to the ATIS weather broadcast by VHF voice radio. A transcript of the broadcast follows:

'This is Hong Kong International Airport. Information Golf at time zero two three five. Runway in use one three. Expect IGS approach. Runway surface wet. Surface wind zero six zero degrees two zero kt, maximum three eight kt. Visibility seven kilometres in rain. Cloud

scattered at one thousand four hundred feet. Scattered at two thousand feet. Temperature two four. QNH one zero one two hectopascals. Expect significant windshear and moderate to severe turbulence on approach and departure. Tempo visibility three thousand metres. Acknowledge information Golf on frequency one one niner decimal one for arrival and one two four decimal six five for departure'.

1.7.6 Runway visual range (RVR)

A system for measuring RVR was operating at the time of the accident, consisting of 3 sets of transmissometers on the southwest side of the runway at a distance of 91m from the runway centreline, with the first set abeam the 13 threshold, the second set abeam the mid-point of the runway and the third set abeam the 31 threshold. The lowest RVR recorded by the transmissometer opposite the 31 threshold was 1,400 metres at 0325 hr which steadily increased to 2,000 metres by 0330 hr and remained at or above this range for the next 30 minutes. The temporary reduction in RVR was attributed to rain drops on the transmissometer optics.

1.7.7 Surface wind measurement

Surface wind at HKIA is measured by 3 sets of distant reading cup anemometers. These anemometers are annotated SE, MID-RUNWAY and NW; their locations are depicted on the airport diagram at Appendix 6. The instantaneous readings from all three anemometers were processed by a computerised wind analyser to give readings of the average surface wind during the previous two minutes and ten minutes. The official wind reported in all observations made at the AMO was taken from the SE anemometer recording (the nearest to the threshold of runway 31). The wind data normally passed by ATC to arriving and departing aircraft was also taken from the SE anemometer unless the winds measured by the NW and MID - RUNWAY anemometers were significantly different, when more than one value would be passed. The wind analyser also calculated and displayed significant deviations in wind speed and direction plus the maxima and minima for crosswind and track wind relative to the runway from all three anemometers. This information was available to the AMC on a television display. The AMC is also provided with wind dials showing the wind directions and speeds measured by the SE and NW anemometers.

1.7.8 Rainfall

Rainfall on Hong Kong is recorded by the Royal Observatory. The records showed that little rain fell on HKIA before 04 0300 hr. During the hour of the accident (0300 to 0400) a maximum of 9 mm of rain fell in the final approach area and 6 mm over Kwun Tong (about 3,000 metres from the runway), with an instantaneous rainfall rate in the final approach area of less than 10 mm per hour.

1.7.9 Pilot reports of weather

The AMC stated that during the morning there had been several pilot reports of windshear encounters during the finals turn. The commanders of two other aircraft stated their recollections of the general weather conditions at HKIA. The commander of a wide-bodied aircraft which landed about 20 minutes before CAL605 stated that at high altitude the wind speed was about 30 kt. His aircraft entered cloud at 28,000 feet and the wind speed increased to 50 kt at 7,000 feet. On joining the IGS approach the wind direction at 4,500 feet was steady at 070° and the speed was between 50 and 60 kt. There was widespread moderate to heavy rain in the Hong Kong area but little significant turbulence until the aircraft descended below 2,500 feet altitude. At a late stage during the finals turn to align the aircraft with the runway, the aircraft encountered a 'vicious rotor' which caused the aircraft to sink below the desired approach slope and which deflected it in roll and yaw. A GPWS warning of 'SINK RATE' was heard and the commander had to make very large control inputs to regain the flight path.

The commander of a Boeing 747 which was parked on the apron at HKIA reported that his aircraft was being buffeted by the strong winds. The wind was gusty and prolonged periods of gusting lasting about 90 seconds accompanied heavy rain squalls. His first attempt to take off had to be abandoned because of a minor fault. The braking action provided by the autobrakes in the rejected take-off mode was good and the aircraft did not slide or skid to any noticeable extent. The second attempt to take off was successful and took place about one minute before CAL605 landed. At the time the rain was heavy but not torrential. The runway was very wet but there were no visible pools of standing water and the runway appeared to be evenly wet in length and width. The nearest wind sock was horizontal and the wind direction was essentially directly across the runway. Shortly after releasing the wheel brakes, the aircraft was hit by a gust and it began to slide sideways for a period of about 10 seconds in an area of heavy rubber deposits close to the displaced threshold of runway 13. The commander used large inputs of nose wheel steering tiller to regain the centreline and thereafter he relied upon almost full rudder and significant into-wind roll control to keep the aircraft straight and level on the runway. He described the weather conditions as challenging but acceptable.

1.7.10 **Windshear at Hong Kong International Airport**

The AIP for Hong Kong contained the following text concerning windshear:

'General Warning

In the vicinity of Hong Kong International Airport, significant low level windshear and moderate to severe turbulence are usually encountered when winds off the hills are around 15 kt or more. Windshear and turbulence should particularly be expected over the NW approach area to the runway when the wind is strong and blowing from between NW and ENE in association with a tropical cyclone or a strong winter monsoon. Shear and turbulence due to these causes are additional to those which should always be expected in proximity to thunderstorms and large cumulonimbus, and in heavy rain or showers.

RWY 13 Approach

With wind speeds of 15 kt or more, caution is required on the approach to RWY 13. Pilots have reported that when the wind is between 090° and 130°, the shear effect can give a marked increase in airspeed abeam the Checkerboard and an abrupt decrease between the approach end of the runway and the displaced threshold. The opposite is often the case when the wind direction is 050° to 070°, a marked decrease in airspeed can occur abeam the Checkerboard and an increase in airspeed near the runway. During the winter months if the wind is from the north, the degree of turbulence to be anticipated on the approach to RWY 13 would normally preclude an approach even though the surface wind speed *may be below the allowable tail wind for landing. When the surface wind direction is from 140° to 220°, particular care will be needed not to overshoot the extended centreline of the runway during the final turn onto RWY 13. Pilots should be aware that although the surface wind may be only 10 kt, the funnel effect of the hills just north of the approach path may result in the wind at 500 ft to 1,000 ft being considerably stronger.'*

1.7.11 Windshear detection system at Hong Kong International Airport

Low-altitude windshear is monitored continuously by the Low-level Windshear Detection system designed by the Hong Kong Royal Observatory. It employs the same microcomputer and anemometers used for runway wind component analysis supplemented by two more anemometers located beneath the approaches to the airport as shown at Appendix 6. The anemometers measure only the horizontal wind components; they are incapable of measuring the vertical air currents likely to occur in the vicinity of heavy showers or thunderstorms.

Wind data from the five anemometers are transmitted to a microcomputer in the Airport Meteorological Office where the change in head-wind component (or tail-wind component) with height on each flight path is computed.

The warning threshold is based on an ICAO recommendation that wind variations which exceeded the limits specified for the certification of automatic landing systems should be measured and reported to pilots.

Whenever the predicted windshear exceeded 8 kt per 100 feet of altitude change, the AMC is alerted and a display indicates whether the windshear is 'sinking' or 'lifting'. This terminology is based on the effect of the windshear on an aircraft if a pilot takes no recovery action. The wind velocity at the anemometers is automatically recorded every 10 minutes in benign wind conditions and every 30 seconds whenever a windshear of 8 kt or greater is predicted.

The AMC stated that on the day of the accident alerts for significant windshear had been triggered throughout the morning at an approximate rate of two alerts every five minutes. A copy of the recorded wind parameters for the period 03:30:00 hr to 03:40:00 hr is at Appendix 7. The absence of recordings at 03:36:00 hr, 03:36:30 hr and 03:37:00 hr infers that any windshear predicted during this period was less than 8 kt/100 feet. The accident aircraft received a warning of sinking windshear from its own GPWS computer at 03:35:15 hr with reference to the ATC clock. The windshear detection system takes its time reference from its own internal clock. It was not possible to determine whether there was a significant time difference between the two clock systems at the time of the accident.

1.8 Aids to navigation

All relevant navigational aids were serviceable during the period of the accident flight.

1.8.1 Approach aids

The approach aid in use at the time of the accident was the instrument guidance system (IGS) to runway 13. The localiser centreline is aligned to 088°M and the glidepath is set at 3.1°. The instrument flight segment of the approach terminates at the middle marker (1.7 NM from touchdown). If visual flight is not achieved by this point, missed approach action must be taken. The missed approach procedure involves a right turn and a climb to 4,500 feet amsl. A copy of the IGS approach chart is at Appendix 1.

1.9 Communications

'Dynasty' is the callsign used by China Airlines. At 0317 hr Dynasty 605 established radio communication with Hong Kong Approach Control on 119.1 MHz and continued on this frequency until 0328 hr when the aircraft was passed to Hong Kong Tower on frequency 118.7 MHz. Continuous speech recording equipment was in operation on both frequencies and a satisfactory transcript of the messages that passed between the accident aircraft and ATC was obtained (see Appendix 8). The transcript shows that radiotelephony (RTF) conversations on frequency 118.7 MHz were conducted in English and proceeded normally. No difficulties in transmission or reception were evident.

1.10 Aerodrome Information

1.10.1 General

The single runway 13/31 at HKIA (a plan of which is at Appendix 9) is situated on a promontory of reclaimed land which is 242.3 metres wide and protrudes into Kowloon Bay. The elevation of the runway is 15 feet amsl and it has no slope. A full length parallel taxiway runs along the eastern edge of the promontory and is separated from the runway by a grass area approximately 69 metres wide. The distance between the centrelines of the runway and taxiway is 111 metres. Operational services at the airport, together with the fire fighting and rescue services, are provided by departments of the Hong Kong Government.

At the time of the accident runway 13 was in use. It has the following characteristics:

Direction	:	135° (magnetic)
Length	:	3,331.5 metres
Width	:	61 metres
Landing distance available	:	2,786.0 metres
Take-off run available	:	3,331.5 metres
Take-off distance available	:	3,444.5 metres
Surface	:	The first 150 metres and the last 91 metres were concrete; the remainder was asphalt. The full length of the runway was grooved.
Runway markings	:	The displaced threshold marks, runway designation numbers, thresholds, touchdown zones, centreline, fixed distance markers, side stripe and runway exits were marked by white paint applied to the runway surface.

1.10.2 Lighting aids

A curved centreline of either red (low intensity) or white (high intensity) lights plus white sequenced strobe lights marked the final approach turn on to the centreline. There were 5 cross bars, either red or white and the outermost cross bar had an orange (sodium) omnidirectional light at each extremity.

Precision approach path indicators (PAPIs) were installed on both sides of the runway 315 metres from the threshold. The system used double wing bars each with four sharp transition three-lamp light units. The nominal approach slope angle was set to 3.1° which gave a minimum eye-height over the threshold of 52 feet.

The runway lights consisted of lead-in, threshold identification, threshold, centreline, wing-bars, runway edge and runway end lights. The taxiways also had centreline lights. The runway centreline lights were colour coded in accordance with ICAO Annex 14. At the time of the accident the high intensity approach lights, runway lights and PAPIs for runway 13 were at maximum brightness; the threshold identification lights, approach sodium and strobe lights were on.

1.10.3 Airport fire service

The airport had two fire stations - a main fire station located near the north-western end of the runway and a sub fire station near the south-eastern end (see Appendix 9). The fire stations were manned 24 hours a day and according to established procedures, the fire services personnel would be brought to immediate readiness when weather was bad. The main fire station was equipped with ten rescue and fire fighting vehicles and two motorized inflatable boats. The sub fire station had three land appliances, one motorized inflatable boat and a rescue launch with fire fighting capability. The rescue launch could carry 250 persons. It also carried eight inflatable life-rafts which had a total capacity of 260 persons.

1.11 Flight Recorders

1.11.1 Flight data recorder

The aircraft was fitted with a Fairchild model F1000 Digital Flight Data Recorder (DFDR). This was a new generation type employing Electrically Erasable Programmable Read Only Memory (EEPROM) as the data storage medium. In order to reduce the memory size requirement this recorder employed a form of data compression. This leads to a variable time duration of recording, which in this case amounted to more than 24 hours. A total of 269 parameters were recorded, 89 of these being of the variable type, and 180 of the discrete (on/off switch) type. The recorder was transported to the premises of the Air Accidents Investigation Branch in the UK, contained in sealed plastic bags partially filled with water (to retard the effects of salt water corrosion), and within the normal type of transportation case. A satisfactory replay was obtained with very few areas of data corruption.

1.11.2 Cockpit voice recorder

The cockpit voice recorder (CVR) fitted was a Fairchild model A100. This used plastic based tape as the memory medium, and was of the endless loop type with a re-cycle time of 30 minutes. The tape was removed and copies were supplied to the investigation team. The allocation of the four channels on the recorder were as follows:

Channel 1 - Captain's microphone and headset audio
Channel 2 - Cockpit area microphone
Channel 3 - Not used
Channel 4 - Co-pilot's microphone and headset audio

This system employed the 'hot microphone' technique whereby the crew microphones were live to the recorder continuously, but not producing a sidetone in the headset. The replay quality was good but whenever there was a transmission from the ground, the sounds from the pilots' microphones were swamped and rendered inaudible. This could have been due to either the system gain of the 'hot' microphones being set too low, or to the pilots displacing the microphones at times other than when they were making transmissions.

A transcript of the CVR extract during the final approach and landing phases is attached at Appendix 10.

1.11.3 **Data presentation**

By using some of the DFDR recorded parameters which produced audible sounds on the CVR, the replayed information from the two recorders was synchronised in time. Graphs of relevant flight data are at Appendix 11. Figures 1 and 2 show selected parameters for the last 3 minutes. Figures 3 and 4 show some significant parameters over the final 72 seconds with relevant CVR comments superimposed.

Figure 5 shows groundspeed, deceleration, heading, engine no. 1 fuel flow, air/ground sense and speedbrake lever position against derived runway position.

Figure 6 shows the engine parameters for the previous landing at Taipei and Figure 7 shows the engine parameters for the landing at HKIA.

1.11.4 **Interpretation of the data**

The data indicated that the approach was turbulent with normal acceleration values from 0.7 to 1.5g. Approaching the outer marker, flaps were selected to 20 and the speedbrake lever was moved from the 'DN' (down) to the 'ARMED' position. About 40 seconds later at 1,600 feet altitude, flaps were selected to 30 and the landing checks were carried out. During these checks there were voice calls of "AUTOBRAKE TWO" and "SPEEDBRAKE ARMED".

The aircraft passed over the middle marker at 670 feet altitude slightly to the north of the localiser centreline. As it crossed the marker the airspeed rose from 151 kt to 179 kt in 6 seconds. During that period ground speed increased by 3 kt to 131 kt, an amber 'WINDSHEAR' annunciation was presented on the PFDs and engine thrust was reduced. A right turn was started about 8 seconds after passing the marker.

Eight seconds after the start of the turn there was a momentary "GLIDESLOPE" aural warning followed by a PFD red 'WINDSHEAR' annunciation accompanied by a siren and an aural "WINDSHEAR, WINDSHEAR, WINDSHEAR" message. The airspeed at the onset of the windshear warning was 149 kt, the ground speed 129 kt, the instantaneous rate of descent about 1,500 ft/min and engine thrust was increasing. As the warning sounded the aircraft's nose was raised and normal acceleration peaked at 1.5g. After the warning the rate of descent reduced progressively to about 540 ft/min and there were three more aural "GLIDESLOPE" warnings. During the finals turn the FMC wind velocity varied between 065°/42 kt and 036°/14 kt.

At about 250 feet altitude the aircraft was affected by a lateral wind gust from the left of about 27 kt which induced a sideways acceleration of 0.14g. Eight seconds later at about 100 feet agl near the airport boundary it was affected by another lateral wind gust which resulted in a 0.2g sideways acceleration, a heading change to the left of 5° in two seconds and a temporary drift angle of 14°. At 100 feet agl and below, radio heights were announced by the co-pilot and the GPWS. Just after the 10 feet call there was a noise similar to the throttles being closed against the stops; at the same time engine thrust parameters started a rapid reduction. The thrust of all four engines was reducing towards idle as the aircraft touched down gently about 480 metres beyond the threshold markers at an airspeed between 172 and 161 kt CAS, a ground speed of 160 kt and a heading of 131° M.

The air/ground sensor changed to ground on touchdown and the speedbrake lever immediately began to move rearwards to 'UP' and then forwards to 'DN'. During the period in which the speedbrake lever was moving there were also changes in engine thrust. About 2½ seconds after touchdown the forward thrust parameters of all four engines started to increase; the period of increasing thrust lasted for about four seconds on all engines except number 4 which accelerated for two seconds. During that time the EPR of number 1 engine increased from 0.988 to 1.037; the EPRs of numbers 2,3 and 4 engines also increased but to a lesser extent. Between five and seven seconds after touchdown, the thrust parameters of all four engines began to decline towards idle.

The aircraft progressed down the runway with the speedbrake lever at 'DN'. Six seconds after touchdown the co-pilot stated he would hold the control wheel and apply roll control; at the same time the control wheels were rotated to at least 53° to the left and the aircraft began to roll to the left. The aircraft reached 7° of left bank and the air/ground sensor changed from ground to air. At the same time the control wheel angle reduced to 14° or less to the left and the aircraft's attitude returned to wings-level two seconds later. There then followed a second cycle of roll input to the left followed by a roll to the left and a second cycle of the air/ground sensor before the aircraft returned to wings-level 12 seconds after touchdown.

After the roll oscillations ceased the co-pilot informed the commander that the autobrakes were not working. Seventeen seconds after touchdown the co-pilot exclaimed "SIR REVERSE"; the groundspeed at the time was 130 kt. Half a second later an audible 'click' similar to the sound of thrust levers being selected to reverse was heard and the speedbrake lever began to move rearwards. Aggressive deceleration commenced 20 seconds after touchdown as all four thrust reversers deployed. In reverse thrust the engine pressure ratios reached a maximum of about 1.16 before reducing, and aircraft retardation generally exceeded 0.3g. Near the end of the runway a left turn was started at a groundspeed of 54 kt. The commander cancelled reverse thrust and speedbrakes at a ground speed of 48 kt, about 6 seconds before the aircraft impacted the water at a speed of about 30 kt.

1.11.5 Engine response

The response of the engines and the positions of individual thrust levers during the landing rollout became significant during the progress of the investigation but thrust lever angle was not recorded on the DFDR. Consequently, recorded data from previous flights were studied to provide a comparison. The data showed that at steady thrust settings, the parameters for all four engines were almost identical with the exception of the EGT of number 4 engine which was slightly higher than the EGTs of the other engines (number 4 engine had significantly more utilisation hours than the other three). The response and behaviour of all four engines during acceleration from mid-range power settings and during deceleration from high thrust settings was also similar.

1.11.6 Aircraft final approach track

Longitudinal and lateral accelerations were integrated to reconstruct the aircraft's final approach track over the land. A map of this final approach path annotated with significant events is presented at Appendix 12.

1.11.7 Runway events

A diagram depicting significant events during the landing roll at corresponding positions on the runway is presented at Appendix 13.

1.12 Wreckage and impact information

At the end of runway 13, up to the edge of the sea wall, evidence of tyre tracks from this aircraft could clearly be seen. These tracks took the form of light coloured marks typical of those produced by the scouring/cleaning action of tyres rolling over a concrete surface in the presence of water. These tracks could be traced back for some 160 metres from the sea wall before becoming indistinct and are shown on a scale drawing at Appendix 14. Several outlines of a B747 (drawn with flaps retracted for simplicity) have been placed over these tracks to indicate the passage of CAL605 over the ground, together with relevant parameters. From the relation of the tracks to the geometry of the aircraft, it was determined that with approximately 120 metres to run, the aircraft had started to turn to the left but that a slight skid had developed to the right, its heading and track being 101°M and 115°M respectively as the nose wheels left the sea wall. At this point the nose wheels were some 50 metres to the left of the runway centreline. The nose wheel tracks also indicated that a large nose wheel steering angle existed at this time and that the aircraft was not fully responding to this demand.

As the aircraft departed diagonally to the left over the edge of the sea wall, it began to pitch down and roll to the right whilst the left wing and left body main gears were still supporting the aircraft on the edge of the paved surface. When leaving the runway, both body landing gear wheel trucks tilted forward beyond their normal limits to the extent that a hard contact occurred between the wheel truck and the oleo strut. Longitudinal cracks on both trucks ran from the areas of contact. As the whole aircraft was now able to drop, this allowed the lower aft section of the No 1 engine and the outboard corner of the outer left flap to strike the sea wall, and the underside of the left leading edge outer flap and the mid portion of the underside of the left outer wing and aileron to scrape along the sea wall edge. At about the same time hydrodynamic pressure caused severe damage to the lower nose section as it struck the sea, forcing the nose gear doors into the wheel well which precipitated a compressive failure almost all the way around the circumference of the fuselage between stations 180 and 260. This foreshortening of the front fuselage precipitated major disruption of the main deck forward cabin where some floor panels and support structure for the overhead baggage lockers failed, allowing most lockers to fall into the cabin.

As the right wing entered the water, the No 4 engine pylon failed in an inboard/aftwards direction about the forward lug attachment bulkhead, but the engine remained attached to the wing by the forward upper strut. The

No 3 engine, complete with its pylon, detached from the wing by fuse pin failure at this time, along with the aftmost section of the inner flap on the right side. In passing over the sea wall the underside of the aircraft's tail and inboard left elevator were also struck, resulting in localised severe damage to, and removal of, part of the structure in the region of the APU. Upward movement of the APU structure caused some crushing damage to the lower rudder. The aircraft briefly came to rest, afloat in a fairly level attitude and with the torn nose section and main deck door sills clear of the water, a short distance (at least several wingspans) off, and to the left of, the runway's end. It was soon blown by the wind back towards the innermost approach lighting structures for runway 31 where further damage was caused to the right horizontal stabiliser trailing edge by contact with the lighting bar structure. Engine Nos 1 and 2 and the left outer wing leading edge were damaged by long-term, wave-induced motion of the aircraft against lighting structures and sub-surface obstructions during the days that it remained at that location. Additional damage was caused to the aircraft during the salvage operation, including removal of the fin by explosive means and by cutting into the floor and landing gear areas for access.

The aircraft's configuration at the time of the accident was established as being with all landing gears down and locked, flaps at the 30 position (full), outboard leading edge flaps deployed, inboard and mid-section leading edge flaps retracted and with all thrust reversers stowed. The main gear tyres were all within acceptable wear limits; several had chevron cuts on the tread surface indicative of normal operation on grooved runways. Both nose wheel tyres had transverse abrasion lines but none of the main gear tyres had burst or locked during the rollout, and none had damage consistent with aquaplaning.

Examination of the whole runway length failed to reveal any evidence that the aircraft had made contact with the ground with any part other than its tyres. There was no fire (see Appendix 15 for Aircraft Damage Examination).

1.13 Medical and pathological information

The flight and cabin crew were apparently uninjured; they were not offered or given a medical examination until several days after the accident.

The seriously injured passenger was in seat 54K of economy class cabin (see Appendix 16). He suffered left shoulder dislocation and was hospitalized for five days. He was hit by a passenger from the rear in seat 55J who was believed to have his seat belt unfastened and stood up at the time of the impact. The seat belt of seat 55J was found to be in good working order after the accident and the seat back of seat 54J was found leaning forward with the right hand side recline mechanism separated in two. This shows that the 55J passenger was thrown forward by impact forces, hitting the seat back of seat 54J to the right and the left shoulder of the passenger in seat 54K. The impact was heavy enough to cause failure of the recline mechanism of seat 54J and the shoulder injury of the passenger in seat 54K.

The passenger in seat 55J sustained minor injuries to his left leg. Eight other passengers - one in the first class cabin, one in the upper deck, one in Zone C, one in Zone D and four in Zone E of the main deck - received minor injuries. The passenger in the first class cabin suffered mild head injury caused by failure of the overhead luggage bins. Others suffered minor head or chest injuries as a result of impact with objects upon deceleration.

1.14 Fire

There was no fire.

1.15 Survival aspects

1.15.1 General

The aircraft ended up in the sea some 100 metres from the runway promontory. It remained afloat and the strong prevailing wind blew it back towards the runway end. The main deck doors were used for evacuation except those over the wings (doors 3L and 3R). All slide-rafts inflated automatically as the doors opened and passengers evacuated in an orderly manner onto the rafts. Rescue vessels and personnel soon arrived on scene and all passengers and crew were rescued within approximately 30 minutes of the accident. Only towards the end of the rescue operation did water start to enter the cabin initially through door 5R, then through door 5L. The water in the runway end area was about 6 to 8 metres deep. The aircraft settled down in a slightly nose up attitude with water up to the wing and horizontal stabilizer (see Appendix 17).

1.15.2 Damage to the aircraft cabin

As the aircraft hit the water, the lower nose section on the right side bore the brunt of the impact. This caused the nose section to buckle between Stations 180 and 260 (see Appendix 15) and substantial damage was incurred to the interior of the first class cabin which was located in Zone A of the main deck. Both the left and right hand side overhead panels forward of doors 1L and 1R caved in downwards. Each panel consisted of five luggage bins mounted on a support rail which was secured to the airframe structure by a number of tie rods. Forces exerted on the tie rods due to the impact and buckling of the nose section caused the rods to fail between Station 200 and 440, and the supporting rails to fracture at Station 280. As a result, the luggage bins fell on seats 2B and 2J which were not occupied at the time of the accident. The floor panels between the inboard seat tracks from Station 220 to 270 were also dislodged by the force of impact. Other damage to the first class cabin included separation, deflection or fracture of sidewall panels, ceiling panels, seat tracks and projector screen. These were, however, of comparatively minor nature in terms of survival aspect considerations. A photograph showing the first class cabin damage is at Appendix 18.

There was little or no damage to the other sections of the aircraft cabin including the cockpit. Although not a requirement (and not recommended in a potential fire situation), passenger oxygen was deployed and all masks dropped with the exception of those in the first class cabin, four in the upper deck and 17 in the main deck mostly in Zone B. Subsequent examination indicated that failure of the masks to drop was due to damage to the supply pipes.

1.15.3 Evacuation

The ditching was unplanned. The crew did not know that the aircraft would overrun the runway until seconds before the impact and no warning could be given to passengers. Upon ditching, the captain shut down the engines, tried to speak to the cabin crew using the interphone system but it was not working. He then went out to check that the upper deck doors were in the automatic position and went back to the cockpit to open the escape hatch and check with the first officer. The first officer discharged the engine fire bottles, switched on the emergency lights, deployed the passenger oxygen system and carried out the evacuation checks from memory. Neither crew used a written check list. They left the aircraft after checking that all had evacuated.

The cabin crew of the flight consisted of a chief cabin attendant (purser), three upper deck attendants and 16 attendants on the main deck of whom three were male crew including the purser. The purser, who was stationed at door 2L, tried unsuccessfully to use the PA system immediately after ditching. He then ran upstairs to the flight deck and, after obtaining permission for evacuation from the captain, went down to open doors 2L and 1L and order evacuation. Meanwhile, passengers were told to keep calm and put on their life jackets by other cabin attendants. All communication was done verbally. The PA system was damaged and megaphones were not used by the crew. Door lR was opened by a male cabin attendant stationed there. The slide-raft at this door was initially blown by the wind and the attendant had to wait for the wind to reduce before going onto the slide-raft to stabilize it. Doors 4L, 4R and 5R were opened by an attendant stationed at door 3L. Doors 2R and 5L were opened by the attendants stationed there. The upper deck and over wing doors were not used and upper deck passengers were directed to evacuate via the main deck as per the company's emergency evacuation instructions.

The accident occurred during day-time. There was no fire, no smoke and water did not enter the cabin for the initial 20 minutes or so, by which time most of the passengers had evacuated the aircraft. The crew had no difficulty in directing passengers onto the slide-rafts except that it took a few minutes for a few passengers in the first class section to make their way out of the partially obstructed cabin. The evacuation was generally orderly although some crew members commented that they had problem in controlling the carriage of personal belongings by passengers. They also had to spend quite some time in assisting passengers to put on their life jackets although donning of life jackets was demonstrated at the pre-departure safety briefing.

1.15.4 Rescue operation

On the day of the accident, the airport fire service was on standby because of the strong winds. Upon receiving the alarm from the air traffic control tower, appliances from the two stations responded quickly. The first vehicle from the sub fire station arrived at the runway end within one minute of the accident followed shortly by others. Ladders were set up on the sea wall and divers with rescue lines headed for doors 2L and 1L which opened first. The rescue launch arrived at the scene in about six minutes and inflatable life-rafts were deployed to attend the slide-rafts with the help of motorized boats. Two rafts attended door 1L and managed to form a 'floating bridge' between the slide-raft and the runway end as the aircraft drifted closer to the runway. Most people evacuated via this route. Persons on the slide-rafts at doors 2L and 4L re-entered the cabin and evacuated via the 'floating bridge' under the direction and assistance of the rescuers. Persons on the slide-rafts at doors 1R and 2R were attended by two other life-rafts and transferred to the rescue launch.

Prior to the arrival of the rescue launch, some vessels in the vicinity proceeded to help. A tug boat first reached the scene and was edging close to the 1L slide-raft when the rescue launch arrived which then took over the rescue. Vessels from the Marine Department and Marine Police also arrived and attended doors 4R, 5R and 5L with help from the small motorized private boats. The slide-raft at door 5R was reported to have been punctured by high heel shoes and was the only raft deflated during evacuation. Persons on it were rescued by a launch attending the door. The slide-raft at door 5L was detached and towed by rescue speed boats to a nearby launch. Other government and military vessels arrived later to assist.

The rescue operation was completed in about 30 minutes and no major difficulty was experienced. Persons needing medical treatment or observation were sent to hospital by ambulances. In addition to the 12 vehicles from the airport fire service, over 25 vehicles and 45 ambulances were dispatched to attend the accident from various fire stations and ambulance depots in town. Photographs of the rescue operation are shown at Appendix 19.

1.16 Tests and research

1.16.1 Aircraft mechanical systems

Data recovered from the Digital Flight Data Recorder (DFDR), Cockpit Voice Recorder (CVR) and Central Maintenance Computers (CMCs) enabled the engineering investigation to concentrate on selected systems in the aircraft, particularly those used to decelerate the aircraft after landing. Systems such as primary flight controls were not given in-depth examination because the aircraft had successfully completed its flight to touchdown, rollout along the runway and it was known, from the DFDR and the flight crew, to be responding sensibly to control inputs. Similar reasoning applied to other areas such as fuel systems, power plants, electrical generation and distribution systems, and landing gear retraction systems. Areas of particular interest for testing were identified as the auto-speedbrakes, wheel brakes, thrust lever controls, thrust reverse controls, windshields, wipers and rain repellent system.

Tests of the aircraft's mechanical systems revealed no abnormalities or failures which would have affected the aircraft's ability to stop or go-around using normal techniques. The conduct and results of the tests are detailed at Appendix 20.

1.16.2 **Central Maintenance Computers**

Shortly after the accident, whilst the aircraft was still in the water, as many as possible of the computers and avionics were removed from the aircraft and put into dry store for safe keeping and possible future interrogation. Amongst these were the two CMCs, which are primarily designed to log defects on the aircraft for maintenance purposes. A visual internal examination of the CMCs, taking due precaution against static discharge, indicated that they had not been damaged or immersed in salt water and they were transported to their manufacturer for readout of the non volatile memories (NVMs). This was successfully conducted in the presence of personnel from the AAIB and NTSB. Few faults had been logged but, of significance, under the autobrakes system both computers had logged a 'PRESENT LEG AUTOBRAKE THRUST LEVER SWITCH 1 FAILURE (BSCU)' at time 03.35 UTC (11.35 local) on 4 Nov 93 during rollout. This was not a true failure but an indication that the autobrake had been automatically disarmed as the number 1 thrust lever was beyond the idle range at a time when it should have been at idle. Other logged faults were dismissed because these were associated with damage to the nose gear and APU areas of the aircraft as it departed over the sea wall.

1.16.3 **Thrust lever angles**

Thrust lever angle (TLA) was not recorded on the DFDR. However, parameters such as fuel flow, N1, N2 and EPR were present and Boeing estimated engine No 1 TLA from this data, in particular for the period from just before touchdown to the early part of the rollout. This was accomplished by matching as close as practicable the N2 response of a PW4056 engine (computer) model to thrust lever movement inputs. A close matching of this response is presented in Appendix 21. This suggests that thrust lever No 1 may have been positioned forward from idle by some 8° for a period of 7 to 8 seconds after touchdown.

The peak reverse thrust (nominally 1.16 EPR) achieved on all four engines 26 seconds after touchdown was considerably less than that achieved during the previous landing at Taipei when reverse thrust rose to 1.273 EPR. The shortfall in reverse thrust was also reflected in engine rotational speeds; maximum reverse thrust is nominally 90% N1 but the peak rpm during the landing rollout was 80% N1.

1.16.4 **GPWS**

The GPWS computer was taken to the manufacturer's facility in the USA where it was tested and found serviceable. The flight data for the approach were analysed by the aircraft manufacturer as follows:

'During the course of the subject analysis, it was discovered that the parameter recorded as a windshear alert discrete by the FDR was the windshear caution alert (sometimes referred to as a pre-alert) discrete, and not the windshear warning discrete. The windshear event lasted approximately 45 seconds between the altitudes of 654

feet and 86 feet AGL. During this time, a windshear caution alert, which is exhibited by the word 'WINDSHEAR' in amber letters displayed on the EADIs was issued at an altitude of 558 feet. Although the data required to reproduce the actual warning alert threshold is not recorded by the FDR, it is known that the warning threshold lies in the region of -0.11 to -0.13g and the total windshear calculation enters that region. The windshear warning, consisting of an aural "WINDSHEAR WINDSHEAR WINDSHEAR" message (as evidenced by the Cockpit Voice Recorder) accompanied by the word 'WINDSHEAR' in red letters displayed on both EADIs, most likely occurred around the altitude of 230 feet AGL.

By examining the vertical component (total windshear is comprised of both a vertical and a longitudinal component) it can be seen that a downdraft, lasting approximately 16 seconds, occurred around the time of the red windshear warning. The longitudinal component responded to an approximate loss in airspeed (true airspeed) of 34 kt over a span of 15 seconds. Both the shape of the total windshear calculation and the substantial downdraft seen in the vertical component are indicative of the characteristics of a classic microburst.'

It should be noted that there were no forecasts or reports of thunderstorms that would normally be associated with microburst conditions. Graphs depicting the windshear event together with radio altitude and IRU computations of wind velocity are presented at Appendix 22.

1.16.5 **Wheel brakes**

Good data on longitudinal deceleration was extracted from the DFDR and this was analysed by the AAIB and by Boeing. From the known characteristics of the aircraft and conditions at the time, elements contributing to the deceleration of the aircraft resulting from inherent drag, speedbrake drag and reverse thrust were calculated in terms of 'g' and superimposed on a plot of measured aircraft deceleration during the landing (see Appendix 23). From this plot, operation of the wheel braking system was determined together with an assessment of the moment when wheel brakes began to contribute significantly to the retardation of the aircraft. From time reference 19 seconds to 0 seconds, there was a large difference between measured and calculated deceleration due to the above factors; a difference which could only be attributable to wheel braking. The effect was understandably dominant as the aircraft approached the end of the runway when reverse thrust was cancelled and aerodynamic drag diminished as the airspeed decayed. Over the time period 19 to 3 seconds the wheel braking retardation contribution peaked at around 0.4g, but reduced to approximately 0.2g over the last few seconds. The reduction in retardation coincided with the period when the aircraft was experiencing yaw to the left/skid to the right towards the end of the runway. Prior to the 19 second point, no wheel braking effect was indicated.

1.16.6 **Runway friction testing**

The runway at HKIA was built with a slight transverse camber to aid water drainage. Approximately 9 months prior to the accident, the asphalt runway surface had been replaced and cut with transverse grooves along its whole length. Approximately 90 minutes after the accident the airport authorities conducted friction measurements of runway 13 using their Mk 3 MuMeter. At the time the runway was reported to have been wet but not to have had standing water on the surface. Three runs were carried out, one along the centreline, and one each 5 metres on either side. Average measured values of friction for these runs were 0.57μ, 0.635μ, and 0.56μ.

During the course of the investigation, it was decided to obtain a survey of the physical state and friction characteristics of the surface. To this end a specialist surveyor was commissioned by the airport authorities; extracts of his report is at Appendix 24. Before these further test runs were made, the airport MuMeter was check calibrated and found to over-read; this was corrected before the test runs were carried out. In summary, the overall friction value of the runway was in the region of 0.55μ, mid way between the ICAO recommended maintenance planning level of 0.45μ for an in-service runway and the minimum for a newly laid runway surface of 0.65μ.

The survey highlighted a small, but potentially significant, runway characteristic in that the measured friction values over areas of white runway marking fell, in places, to that usually associated with ice (approximately 0.05μ - 0.06μ). From the DFDR data, it was apparent that late in the rollout, some 9 to 7 seconds before the nose wheels left the paved surface, the recorded longitudinal deceleration decreased from a value of around 0.4g to around 0.2g for approximately 2 seconds. A short run was made to investigate the friction levels at the 31 threshold, at an angle across the end of the runway following the track of the accident aircraft. The run speed was 40 mph (35 kt) with 0.5 mm of water depth beneath the tyres. Across the 'piano keys' the friction value dropped to below 0.1μ, followed by a rapid rise to 0.78μ across the diagonally grooved 50m section of concrete, reducing slightly to 0.7μ on the final 91 metres of grooved concrete.

1.16.7 **Flight simulation**

The weather conditions and circumstances surrounding the accident were replicated in full flight simulators in Hong Kong and London and in an engineering simulator at Seattle to gain a better understanding of the pilots' tasks and difficulties. Pilots with previous jet aircraft handling experience had no problem in controlling the aircraft in roll on the runway. Speedbrake and autobrake responses to thrust lever handling were replicated and the sensitivity of the nose wheel steering tiller was experienced. Late rejected landings and maximum braking effort stops were performed successfully from abeam the A10 exit at 130 kt groundspeed.

1.17 Additional information

1.17.1 **Flight crew manuals**

The flight manual, operations manual, quick reference handbook, and flight crew training manuals used by China Airlines' Boeing 747-400 fleet were prepared and issued by the Boeing Company. The Airplane Flight Manual was Boeing document No D6U10001 dated Jan 10 1989, last revised September 10 1993. The Operations Manual was Boeing Document No D6-30151-416 dated August 15 1989, last revised September 2 1993. The Quick Reference Handbook (QRH) was a Boeing Flight Test Airplane Copy for airplane block no RT 635 issued 6.2.93 and endorsed 'Not to be kept up to date'. The Flight Crew Training Manual (FCTM) was Boeing Document FCT 747-400 (TM) Revision 2 dated June 10, 1991.

Note : The QRH found on the aircraft was originally placed there by Boeing for flight test purposes only and should have been replaced by the airline with an up-to-date copy supplied by Boeing in July 1993.

China Airlines made no changes or additions to these manuals other than routine amendments supplied by the Boeing Company. Additional instructions from the airline to its flight crew were contained in China Airlines' own B747-400 Standard Operating Procedures (SOPs) and Flight Hand Book. The Flight Hand Book was carried on the flight deck of the accident aircraft but the SOPs were not.

The SOP document consisted of 11 pages of A5 size paper. Most of the headings and paragraph titles were in English but the amplifying remarks were in Chinese. The SOPs were essentially a summary of operational procedures and appeared to contain little more than a distillation of the procedures itemised in the Operations Manual provided by Boeing. The section covering approach briefing, descent and landing occupied 16 lines of characters.

The Flight Hand Book contained glossaries, flight crew duty time limits, numerous extracts from the Boeing Manuals, company routes, company fuel policy and information pertaining to major destinations in the USA and Canada. There were no pages for airports in Asia.

The Flight Hand Book also contained the airline's crosswind limitations for the aircraft types in its fleet. The crosswind limits for landing the Boeing 747-400 were: 30 kt on a dry runway; 25 kt on a wet runway with no standing water and 10 kt on a runway contaminated by slush or standing water. Notes to the tabulated limits stated:

1. *Due to the distance between the runway and taxiway in Hong Kong airport is slightly less than that recommended by ICAO, the landing crosswind limitation should be reduced to 25 kt for dry runway and 22 kt for wet runway (all type of aircraft 90 ° wind direction) at Hong Kong airport).*

2. *The wind velocity shown above is based on steady wind, for flight safety reason PIC may make decision whether or not when steady wind is within cross wind limitation while the gust is over."*

China Airlines also provided a plastic covered, double-sided briefing reminder for use by the crew when briefing before take off or landing. This card was carried and stowed in a readily accessible position on the flight deck together with the normal checklist card. A reproduced copy of the approach briefing chart is at Appendix 25.

1.17.2 En-route and approach charts

The en-route and approach charts used by China Airlines were supplied by the Jeppesen company. The airline made no changes or additions to the Jeppesen manuals other than incorporating routine amendments supplied by Jeppesen. The airline did not provide its flight crew with supplementary airfield briefing material or company instructions regarding company procedures at specific airports other than airports in the USA and Canada.

1.17.3 Missed approaches

ATC record missed approaches and landings at HKIA. A tabular summary of the missed approaches during the morning together with the reason recorded in the log follows:

Time	Reason recorded
03 2235	Strong crosswind
03 2240	Strong crosswind
03 2244	Windshear on final
03 2252	Windshear on final
04 0054	Windshear on final
04 0123	Windshear on final
04 0206	Windshear on final

1.17.4 Successful landings

During the morning there were 25 successful landings excluding the accident flight. Of the 25 aircraft, 20 were large wide-body types of which 7 were Boeing 747 variants. The first successful landing occurred at 0026 hr (0826 hr local) and the landing which preceded China Airlines flight 605 occurred at 0331 hr.

The ATC watch supervisor, the AMC and several pilots stated that during the morning they had observed aircraft which had apparently encountered difficulties during the late stages of their final approaches. The difficulties were described as 'buffeting', 'snaking' and 'rolling'. Some aircraft had gone around from low altitude and landed from a second approach. No pilot had reported control difficulties after touchdown but there had been reports of moderate to poor braking action.

1.17.5 **Additional flight data**

Data from the quick access recorder of a wide bodied aircraft which encountered windshear during the final approach to runway 13 some 30 minutes before the accident were recovered. The data were analysed to provide a comparison of the wind conditions at that time to those prevalent during the final approach of CAL605. It was not possible to determine wind speed from the available data. However, before the finals turn by the checkerboard, the data showed rapid changes in airspeed and angle of attack but no prolonged trend of increasing or decreasing airspeed consistent with windshear. Shortly after starting the turn onto finals, the airspeed fluctuations became larger and more erratic with excursions of up to 11 kt. On a heading of 112°M at 400 feet amsl the aircraft was subjected to gusts with vertical and horizontal components which resulted in rapid excursions of heading, angle of attack, lateral g, normal g and airspeed. The penultimate gust which occurred at about 220 feet amsl on the runway heading of 135°M induced a sink rate warning from the aircraft's GPWS and a rate of descent which exceeded 1,000 feet per minute for six seconds despite early corrective action with pitch attitude and power. During this gust encounter there was a rapid and sustained loss of airspeed of about 15 kt but no substantial reduction in normal g and no significant lateral g forces.

1.17.6 **Human factors**

The assistance of an experienced aviation psychologist was obtained to examine some of the human factors and performance aspects of this accident. A copy of his report is attached at Appendix 26.

2 ANALYSIS

2.1 Scope

2.1.1 The combined wealth of eye witness reports, recorded data, crew interviews and wreckage analysis enabled a very detailed reconstruction of the process which led to the accident. The reconstruction draws upon all the available evidence to define what happened and the order in which significant events occurred. The serviceability of the aircraft was considered and found satisfactory leading to the deduction that the causal factors were probably aspects of the weather, the airport, the performance of the flight crew or the design of the aircraft. Relevant aspects of the weather and the airport are identified and analysed before the human factors are examined in detail. Opportunities for worthwhile changes and additions to the crew procedures and the aircraft systems are reviewed. Throughout the analysis, factors which may have contributed to the accident are identified and where applicable, safety recommendations are made. The analysis concludes with a list of the findings and a summary of the safety recommendations.

2.2 Reconstruction of the accident

2.2.1 Intermediate approach

Flight 605 appears to have been a routine operation until the intermediate approach phase when weather associated with the tropical storm increased the flight crew's workload. The major difficulties were turbulence below 2,500 feet altitude, rain which reduced visibility and would reduce runway friction, the well-known problem of windshear on final approach to runway 13 and a strong crosswind which was close to the operator's stated maximum. At 1,100 feet altitude the aircraft was aligned with the IGS and the average airspeed in the gusty conditions was very close to the commander's target approach airspeed of 153 kt. When he issued clearance to land, the AMC stated the surface wind as 070° at 25 kt and reminded the crew to expect sinking windshear on short finals. The co-pilot acknowledged the clearance and repeated the word "WINDSHEAR" to the commander. The commander then disconnected the autopilot and autothrottle, and commenced controlling the aircraft manually.

2.2.2 Final approach

The first unusual event was the commander's apparent inability to read V_{REF} on his PFD which should have been indicated by a magenta coloured index. The reason for his difficulty was not established but the problem was rapidly overcome by the co-pilot who re-entered the speed into the FMC and then began a voice commentary of speed which he continued sporadically until touchdown. The next event which troubled the pilots was the appearance of the amber windshear caution message on the PFDs. The commander noticed this message and used the word "windshear" in spoken remarks which included a comment on the bad weather. At this stage the airspeed was at least 20 kt higher than his target of 153 kt and the aircraft had drifted slightly above the IGS glidepath; consequently he reduced engine thrust and aircraft pitch attitude at the same time. Seven seconds later, as he approached the 'checker board' with average airspeed still above target, the commander started the right turn onto short finals. The turn was to last 25 seconds and take the aircraft over Kowloon Tong at about 400 feet agl; during the turn the mean relative wind direction would have changed from 15° left of the aircraft's nose to 60° left of the nose. From the start of the turn to the point of touchdown, the turbulence was such that large, frequent, pitch and roll control inputs were required to control the aircraft's attitude.

2.2.3 **Windshear encounter**

Five seconds after the start of the turn, airspeed began to decay, the aircraft pitched down, normal g reduced well below unity and the rate of descent began to increase markedly. As they did so, the commander began to increase pitch attitude and thrust. Three seconds later the GPWS aural "GLIDESLOPE" warning sounded once on the cockpit loudspeakers. This was followed immediately by an aural warning of "WINDSHEAR, WINDSHEAR, WINDSHEAR". As the "GLIDESLOPE" warning sounded, the commander vigorously raised the aircraft's nose and advanced the thrust levers somewhat less vigorously; at this stage the aircraft was 260 feet agl with a sink rate of some 1,600 feet per minute and the airspeed was on target. Neither pilot said anything when the aural "WINDSHEAR" warning sounded, no attempt to go-around or execute a terrain avoidance manoeuvre was apparent and engine thrust peaked well below maximum. The co-pilot saw the written warning of 'WINDSHEAR' on his PFD and the master caution warning light remained on for the next five seconds. When the master caution warning ceased the aircraft was some 70 feet below the 3.1° glidepath indicated by the PAPIs and 150 feet above the sports ground at Kowloon Tsai Park.

2.2.4 **Lateral gusts**

After the windshear encounter the commander continued the turn in silence at a rate of descent of about 700 feet per minute and the aircraft slowly closed towards the correct glidepath from beneath it. There were three more calls of "GLIDESLOPE" from the GPWS and the co-pilot continued to call airspeed relative to target. Airspeed reached a minimum 143 kt (10 kt below target) in a lateral gust 130 feet above Kowloon City. A second lateral gust at 100 feet as the aircraft passed abeam the airport terminal caused a significant undemanded yaw to the left, a small pitch down and a sideways acceleration of 0.2g. The commander took rapid corrective action and regained a wings-level attitude 50 feet above the displaced runway threshold. At 20 feet agl the aircraft's heading was 128° M (7° left of runway heading) which was consistent with the 'crab angle' crosswind approach technique. When the co-pilot called "TEN" (meaning a radio height of 10 feet) the commander closed the thrust levers, applied right rudder and flared gently achieving a soft touchdown slightly right wing low on a heading of 131°M (4° left of runway heading).

2.2.5 The landing

The main gear wheels first touched down about 2,300 metres from the southeast end of the runway and some 480 metres beyond the displaced threshold with thrust levers closed. At the time the mean airspeed was 9 kt above the commander's target although the groundspeed was steady at 160 kt. As the aircraft's weight settled onto the main gears, the speedbrake lever motored rearwards to deploy the speedbrakes, autobrake activated and the nosewheels were lowered to the runway. The commander did not select reverse thrust immediately. Two or three seconds after touchdown all the forward thrust levers were advanced slightly and engine EPR increased accordingly (DFDR indicated No 1 engine EPR increased from 0.988 to 1.037). The amount of forward movement was sufficient to operate a microswitch on No 1 thrust lever designed to detect when the lever was out of the idle thrust range. The operation of this microswitch deactivated the autobrake and motored the speedbrake lever from the UP position to the DN position which retracted all the speedbrakes. Neither pilot noticed the autobrakes disarm nor the speedbrake lever move.

2.2.6 Roll excursions

Five seconds after touchdown, without any verbal prompt or instruction from the commander, the co-pilot said in Mandarin Chinese words which literally translate to "I ROLL STICK". The control wheel was then rapidly rotated to the left and the aircraft started to roll from wings-level to a maximum of 7° left bank. This was sufficient to cause the right main gears to lift and tilt thereby changing the air/ground logic in the Proximity Sensor Electronics Unit (PSEU) to air, but it was insufficient to cause number 1 engine pod to strike the ground. As the aircraft rolled the commander said in Mandarin to the effect "WAIT, DONT ROLL TOO MUCH". At the same time he grasped his own control wheel, reduced the amount of into-wind roll control applied, and retarded the thrust levers. The aircraft returned to an even keel whereupon the co-pilot again rotated his own control wheel into wind, this time to a slightly greater angle than before. The aircraft started to roll to the left reaching 6° of bank and again the air/ground logic changed to air. This time the commander said in Mandarin "DON'T ROLL TOO MUCH" in a more forceful tone of voice and he physically reduced the co-pilot's control input to restore the aircraft to wings level. As the aircraft returned to wings level once again, the co-pilot responded in Mandarin words which translate to "I HAVEN'T I HAVEN'T ROLLED". At this stage the flight deck was 1,365 metres from the end of the runway and passing abeam the A9 exit; the engines were at idle forward thrust, the speedbrakes were retracted, there was no manual or automatic wheel braking and the groundspeed was 139 kt.

2.2.7 Aggressive deceleration phase

Four seconds after the aircraft finally returned to wings-level the co-pilot saw the EICAS advisory message 'AUTOBRAKES' and said to the commander in a mix of Mandarin and English "AUTOBRAKES WE DON'T HAVE". At this stage the flight deck was 1,080 metres from the end of the runway, the groundspeed was 133 kt and the deceleration was less than 0.1g. Two seconds later the co-pilot said loudly in English "SIR REVERSE". The reverse thrust levers were raised within one second of the co-pilot's call which was 18 seconds after touchdown. At that time the aircraft was decelerating through 129 kt ground speed some 880 metres from the end of the runway. Because reverse thrust was selected, the speedbrake lever was automatically raised out of the 'DN' detent and motored to the 'UP' position thereby extending all the speedbrakes. A second or so after that, the co-pilot said softly to himself in Mandarin "OH NO,OH NO" and then, with 750 metres of runway remaining, a period of aggressive wheel braking commenced during which both pilots pressed hard on their respective brake pedals. All four engines accelerated in reverse thrust but none reached the maxima for the prevailing conditions (approximately 1.33 EPR and 90% N1).

As the aircraft crossed the threshold markers of runway 31 some 220 metres from the end of the runway, reverse thrust began to decrease and left rudder pedal was applied. Some 120 metres from the end at a groundspeed of 60 kt the nose wheels started to slide sideways and the nose wheel steering tiller was used to demand full left turn. Seventy metres from the end of the runway, as the aircraft approached the last exit, the speedbrake lever was manually returned towards the 'DN' position and reverse thrust was cancelled. At this point the commander vocally expressed despair. The aircraft slewed to the left and ran off the end of the runway at 30 kt groundspeed just as the thrust reversers stowed and the speedbrake lever reached the 'DN' position.

2.2.8 After water entry

Neither pilot was hurt on impact with the water. The commander operated the engine fuel cut-off switches and the co-pilot operated the engine and APU fire handles.

The aircraft entered the water in a slightly nose down attitude. The final decelerations of the aircraft could not be determined as the Digital Flight Data Acquisition Card (DFDAC) was damaged as the aircraft entered the water and as a result, the DFDR data on the final vertical and lateral accelerations were invalid. Damage in the first class cabin was caused by impact of the lower nose section with the water as the aircraft ditched and not by inertia loads due to deceleration. This impact resulted in body deformation which produced a combination of in-plane and out-of-plane loading on the overhead bins and their supports and the floor panels in excess of their capability. These components are not designed to be loaded by their supporting structure when this structure is loaded beyond its design limits. The aircraft remained largely intact and in spite of damage caused to the lower part of the nose and tail section, water did not enter the main cabin for some 20 minutes. This avoided panic, gave time for passengers to put on life jackets and allowed evacuation to be conducted in an orderly manner.

Since this was not a planned ditching, pressurization outflow valves were open and water entered the aft cargo compartment through the open valves, as well as entering the unsealed fuselage aft of the pressure bulkhead causing the aft end of the aircraft to gradually settle in the water. Water entered the main cabin via door 5R where the slide-raft had deflated, reportedly punctured by high heel shoes during evacuation, and via door 5L where the slide-raft was detached. By this time nearly all on board had exited the cabin and the aircraft drifted close to the runway end. Although an established procedure exists for cabin attendants to order high heel shoes off when using the slide-rafts, effective control might not be possible in a real accident environment. The possibility of using stronger material for slide-rafts to reduce the risk of damage by objects such as high heel shoes may be worth investigating.

Proximity of the aircraft to the runway end facilitated rescue work. Flotation of the aircraft is a key element in determining the survivability of an accident in the water and it is believed that, although not designed to do so, slide-rafts when inflated and attached to the aircraft served as an effective means of preventing water from entering the main cabin. This was particularly so in the case of the aft entry doors where the door sill is nearest to water according to the designed floatation characteristics of the airplane and as proved by the accident.

Of the damage to the aircraft cabin, only that in the first class cabin was likely to cause serious injury and obstruct evacuation. Judging from the extent of damage, serious injuries might have resulted from the falling overhead panel if seats 2B and 2J had been occupied. Also, the missing floor panel might have caused obstruction to evacuation or injury if the accident had occurred at night.

2.3 Aircraft serviceability

The wealth of recorded flight data coupled with the absence of any reported handling problem during the approach were sufficient to establish that both the primary and secondary flight controls were responding correctly to demands made by the flight crew. The windscreen wipers could be heard working on the CVR, the windscreens were in excellent condition and rain repellent was available had the pilots decided to use it. All four engines responded to thrust lever movements in forward and reverse thrust and the commander's statement supported the DFDR data which indicated that autothrottle and autopilot remained disengaged throughout the final stages of the approach and the landing roll. There were no indications of faults in the hydraulic and electric systems and the landing gear had extended normally. The GPWS gave timely warnings of both the increase and the decrease in aircraft energy due to windshear which both pilots saw on their PFDs and the audio warnings of "GLIDESLOPE" and "WINDSHEAR" were loud and clear on the CVR area microphone channel. On touchdown the PSEU correctly sensed that the aircraft had landed which allowed the automatic speedbrake function to operate. The return of the speedbrake lever to the DN position was triggered by the advancement after touchdown of the No 1 engine thrust lever by at least eight degrees; this was a design function which operated correctly. Shortly after touchdown the deceleration force reached a level consistent with the autobrake setting but then the deceleration force reduced as the autobrakes were disarmed by the same thrust lever movement which retracted the speedbrakes. The EICAS detected and displayed the disarmament of the autobrakes. The commander stated that he had no difficulty in obtaining reverse thrust when he selected it, although the level of reverse thrust achieved was less than maximum. When both pilots applied the wheel brakes using their foot pedals, aircraft deceleration was consistent with good brake performance on a wet asphalt surface. All the tyres had been in acceptable condition, none had locked or deflated and several showed surface distress consistent with heavy braking. Marks on the nose gear tyres and on the runway indicated that nose wheel steering had operated normally and to its full angular travel.

The data were sufficient to establish beyond all reasonable doubt that the aircraft was serviceable in all respects relating to its ability to go-around or land from the IGS approach.

2.4 Weather

2.4.1 Relevance

After touchdown the crew of flight 605 had some 2,300 metres of runway in which to dissipate 160 kt groundspeed. Calculations show that a mean deceleration of 0.15g would have been sufficient to ensure that the aircraft could turn off safely at the last available exit. All the stopping aids were serviceable and when they were used, they produced a combined deceleration of 0.3g; the wheel brakes alone produced a stopping force of at least 0.2g. Had the crosswind component during the landing run exceeded the aircraft's capability, the commander might have experienced greater difficulty in retaining directional control and the aircraft would have tended to roll to the right. There were roll control difficulties but these were induced by the co-pilot who applied excessive left roll demand. Therefore, the weather conditions were not directly responsible for the runway over-run. The weather was, however, the principal factor which made the approach more difficult than most for the crew. Turbulence, windshear, strong crosswind, lateral gusts and rain all added to the commander's workload and probably affected his thought processes. Consequently, a detailed analysis of the weather is appropriate to place in context its contribution to those factors which did cause the accident.

2.4.2 General conditions

While descending through 10,000 feet in heavy rain and turbulence, one of the flight attendants instructed the passengers via the PA system to fasten their seat belts. The sound of rain striking the windscreens at 10,000 feet was audible on the CVR but the sound was intermittent in intensity and faded soon afterwards. The rain was probably widespread but heaviest in or beneath cumuliform clouds; this deduction is consistent with the structure of the cloud layers reported in the AMO's routine observations and with witnesses' observations in the air and on the ground. The sound of the windscreen wipers moving during the IGS approach was audible on the CVR and it was raining at the airport when the aircraft landed. The measured total rainfall during the hour 0300 to 0400 did not exceed 6 mm in the airport area and it varied between 4 mm and 9 mm in the greater Kowloon area: the instantaneous rainfall rate in the vicinity of the airport did not exceed 10 mm per hour, while the commander of the Boeing 747 which took off just before CAL605 landed stated that the rainfall was not sufficient to create pools of water on the runway. The combined evidence supports a deduction that the rain was varying between light continuous rain and periodic heavy rain in passing showers. This is consistent with the 0330 hr observation from the AMO.

Visibility must have been at least 3,000 metres because the AMC saw the aircraft enter the sea from his position in the ATC Tower. The co-pilot saw the approach lights before the commander disconnected the autopilot at 1,100 feet altitude indicating that the aircraft was beneath all significant cloud from that point onwards. There were no witness reports of thunder, hail or lightning in the area and the experienced commander of flight 605 did not identify any weather radar returns in the vicinity of the airport which he thought typical of a thunderstorm, although he did see such returns over the sea. The AMO had not forecast thunderstorms or cumulonimbus clouds and there were no observations of them in the routine reports. Therefore, the weather conditions encountered by flight 605 were very similar to the forecast and observed weather reports made available to the crew before and during the flight. On that basis, unexpected weather conditions were not a causal factor.

2.4.3 ATIS

During the approach the crew of flight 605 were informed by ATC that ATIS 'GOLF' was current. Although the weather information contained in ATIS 'GOLF' timed at 0235 hr was little different to that experienced by flight 605 at 0335 hr, routine weather reports were issued by the AMO every 30 minutes. These reports were circulated to various agencies including the staff in the ATC Tower who used them when formulating the content of each ATIS message. However, it was common practice that, if in the opinion of the staff any changes from the previous weather report were insignificant, the ATIS broadcast was not updated.

This practice presupposes that ATC and pilots agree on what is significant, which may not always be the case. For instance, when deciding whether a strong crosswind was acceptable, a sensible pilot would consider the mean and the extremes of both wind direction and wind speed. On the day of the accident the wind was the dominant weather condition but the variations in wind direction that were published in the 0230 hr and 0300 hr AMO observations were not included in the ATIS broadcast. Also, the maximum wind speed in the ATIS was 38 kt which did not accurately reflect the 45 kt and 41 kt maxima in the 0230 and 0330 hr observations. When the crosswind is close to an aircraft's limits such small differences can be significant. Good aviation practice dictates that flight crews are given the information they need. It may be argued that ATC will pass the latest weather details during the approach but this is a busy period for pilots. They may not have the time or the spare mental capacity to re-calculate crosswind components or consider fully the implications of subtle changes in the weather. It follows, therefore, that the ATIS should always be updated every time a weather observation is received. A recommendation to update the ATIS every time a weather report is received from the AMO was made to the Hong Kong ATC authorities shortly after the accident.

2.4.4 Wind conditions

The wind reported in the AMO observations and in ATC reports to aircraft was normally taken from the SE anemometer as readings from the NW anemometer, although nearer the threshold of runway 13, were often affected by local topography. However, from the ATC transcript it can be seen that the AMC was passing the 'touchdown wind' to arriving aircraft. He was scanning the wind readings but could not recall whether he was reporting the SE or the NW reading. His recollection of the average wind was 060° at 20 to 25 kt. This is more consistent with the 2 minute mean at the NW anemometer than at the SE anemometer and so he probably passed the NW anemometer reading to arriving traffic, such deviation being allowed under local ATC procedures. The touchdown wind passed to CAL605 at about 0334 hr was 070°/25 kt which equates to a crosswind component of 22.7 kt from the left. This was just outside China Airline's limit of 22 kt for landing the 747-400 on a wet runway at Hong Kong but well within the limitation of 25 kt for other wet runways.

2.4.5 Gust strength on final approach

Using DFDR parameters it was possible to calculate the wind velocity whilst the aircraft was airborne. At 1,000 feet altitude the wind was from 070° at 40 to 50 kt. Between 1,000 and 500 feet altitude the wind direction stayed fairly close to 070° but the strength varied between 20 and 50 kt. After the windshear encounter the wind direction became far more random until 50 feet agl and below when it settled down to about 060° at 11 to 25 kt. Two gusts on short finals which corresponded to periods of significant lateral acceleration were calculated to give peak winds of 034°/29 kt at 210 feet and 040°/39 kt at 102 feet above touchdown elevation. CAL605 was cleared to land at 0333:58 hr; the wind recording closest in time to this was annotated 0334:00 hr which, if there was no significant time difference between the ATC and the wind analyser clocks, would equate to the time that CAL605 was on short finals. The recording shows an instantaneous reading of 070°/27 kt at the NW anemometer which is reasonably consistent with the second gust measured by the aircraft. The sum of the evidence indicates that CAL605 was subjected to lateral windspseeds of up to 39 kt between the heights of 210 and 100 feet on final approach.

2.4.6 Windshear

The existence of windshear related to strong winds with a northerly component was documented in the Hong Kong AIP and re-iterated on the Jeppesen chart used by the crew. The reader was advised firstly that the effect of the shear conformed to a pattern dependent on the wind direction, and secondly that airspeed changes should be expected between the runway and the checkerboard. The windshear detection system was designed to detect the horizontal winds and the changes thereof between different heights, i.e. it measured the vertical shear of horizontal winds only. The system had been predicting significant windshear for much of the morning and its output was used by ATC to forewarn arriving crews. Most of the go-arounds earlier in the day had been caused by difficulties between the checkerboard and the runway, difficulties which, to the air traffic controllers, seemed to affect nearly all arriving aircraft in the last few seconds of their approaches. However, the shear which triggered the accident aircraft's windshear warning system developed much earlier in the approach. The encounter began overhead Shek Kip Mei and finished 30 seconds before touchdown abeam the checkerboard. Other aircraft approaching did not report difficulty in this region and there was no indication within the data obtained from another aircraft of shear in that area.

The windshear which triggered the GPWS was the type mentioned in the AIP as well as vertical winds, but not the type predicted through the wind analyser by the windshear detection system. Its origin was unlikely to have been a microburst as there were no cumulonimbus clouds in the area and evidence from the wind analyser indicates that some form of weather transient may have crossed the airport shortly after CAL605's GPWS windshear warning. The wind recordings for the NW and SE anemometers beginning at about the time CAL605 received the GPWS windshear warning are presented in the table below:

	NW ANEMOMETER			SE ANEMOMETER		
Time	Instant wind	2 min mean wind	10 min wind speed extremes	Instant wind	2 min mean wind	10 min wind speed extremes
03:35:00	060°/21	070°/22	09 to 37 kt	070°/23	060°/23	12 to 39 kt
03:35:30	060°/37	060°/23	09 to 37 kt	070°/21	070°/23	12 to 39 kt
03:37:30	070°/21	070°/18	09 to 44 kt	060°/28	060°/20	07 to 39 kt
03:38:00	050°/12	060°/17	09 to 44 kt	070°/33	060°/23	04 to 39 kt
03:38:30	060°/13	060°/15	09 to 44 kt	040°/23	070°/25	04 to 39 kt
03:39:00	030°/11	060°/14	09 to 44 kt	060°33	060°/27	04 to 39 kt
03:40:00	040°/17	060°/12	08 to 44 kt	060°/22	060°/25	04 to 39 kt

At the start of the period the 2 minute mean wind direction was close to 065° at both ends of the runway. After the gust to 37 kt at the NW anemometer at 03:35:30, the trend of decreasing mean wind speed there for the next 3½ minutes contrasts with that of increasing mean speed at the SE anemometer.

Like the wind changes across the airport, the windshear which triggered the aircraft's GPWS 32 seconds before touchdown was also chiefly a change in wind speed. The wind direction remained essentially constant at about 065° as did the aircraft's heading which was easterly. It was the speed increase of 25 kt in 10 seconds followed soon afterwards by the reduction of 34 knots in 15 seconds which provoked the warning and caused the rapid sink rate which the commander had to arrest with vigorous control inputs. Given the relative timing, the similarities in wind speed changes and the consistency of the wind direction, both events could have been caused by the same weather transient which was probably a passing squall or heavy shower.

2.5 Hong Kong International Airport

There were two aspects of the existing infrastructure at HKIA which although not causal factors to the accident, are worthy of comment. These were the windshear detection system and the friction characteristics of the runway.

2.5.1 Windshear detection system

Through being optimised for the unusual curved approach to runway 13, the windshear detection system compared wind components along track before and after the finals turn. However, a difference along track does not necessarily indicate windshear. The limitations of the system logic are best illustrated by the outputs from the wind analyser which were used by the windshear algorithm.

At 0335 hr, when flight 605 was on approach, the windshear algorithm was comparing the 2 minute mean winds from the YYC and NW anemometers. These winds were 060°/24 kt and 070°/22 kt respectively. Between the two there was a difference of 10° in direction and two knots in speed resulting in a velocity difference of 4½ kt. Given the 50 metre difference in height between the anemometers and the 2000 metre distance between them, the potential for shear appears to be 2.7 kt per 30 metres vertically or 1.35 kt per 600 metres horizontally. Both levels of shear fall well within the ICAO agreed criteria for light windshear and would have little effect on aircraft control. The windshear detection system, however, resolved the similar winds into headwind components of 21 kt relative to the IGS track and 10 kt relative to the final approach track. It is this 11 kt difference in headwind components which the software used to predict 'sinking windshear' of 8 kt per 30 metres change in altitude; by ICAO criteria, this is the threshold of moderate windshear which may have significant effect on aircraft control.

Although flawed, the logic of the windshear detection system does not negate its value; the system has a proven record of predicting the probable trend of airspeed change due to wind effects between the checkerboard and the runway 13. However, the system logic for runway 13 and the comparison of just two anemometer horizontal outputs constrains the system's ability to detect true windshear in the area of the finals turn. This is the area where lift margins are reduced by the aplication of bank and where susceptibility to windshear and down drafts are increased by the proximity of high ground.

2.5.2 Runway friction

At the time of the accident the runway was undoubtedly wet but the commander of the aircraft which took off just before flight 605 landed saw no puddles of water. The runway friction survey showed that the grooved and cambered asphalt surface, when wet, retained an acceptable coefficient of friction over most of its length and width despite the heavy rubber deposits in the touchdown zones. This was borne out by analysis of the wheel braking effect during the last 800 metres of flight 605's landing roll when the retardation due to wheel braking alone exceeded 0.2 g for most of the time. The only areas that were slippery were those painted white, particularly the 'piano keys' at the Runway 31 threshold. There the paint was very smooth and lacked any friction additive. However, calculations showed that had the white markings been applied with a paint which has similar friction characteristics to the surrounding area, the aircraft would not have been able to stop simply due to improved friction as it crossed the 'piano keys'; it would have run off the end of the runway at a slightly lower speed. Therefore, the use of low friction paint for the runway markings was not a causal factor in the accident. Nevertheless, it was recommended to the airport authorities that the white runway markings should be re-painted with a more suitable paint.

2.6 Flight crew procedures

The remainder of the analysis examines flight crew procedures such as approach planning, content of standard procedures, adherence to standard procedures, the timing of vital actions and procedural errors made by the flight crew.

2.6.1 The approach briefing

The Boeing Flight Crew Training Manual (FCTM) for the 747-400 states:

'Thorough planning and briefing is the key to a safe, unhurried, professional approach. Prior to the start of an instrument approach, the pilot flying should brief the other pilot as to his intentions in conducting the approach, and both pilots should review the approach procedure. All pertinent approach information including minimums and missed approach procedures should be reviewed and alternate courses of action considered.'

The commander's approach briefing was given well before the accident, the tape recording of which was overwritten by the normal cycle of the CVR and could not be assessed. However, both pilots stated that it was given in accordance with the airline's approach briefing reminder card. This card covered most of the applicable topics for the approach. The commander's decision, his assessment of the effects of weather on the approach and landing, and his briefing to the co-pilot are analysed in the paragraphs which follow.

2.6.1.1 Calculation of final approach speed

Page 56 of the FCTM stated:

'The Boeing recommended approach speed wind correction is 1/2 the steady headwind component plus all of the gust value, based on tower reported winds. The maximum wind correction should not exceed 20 knots. In all cases, the gust correction should be maintained to the touchdown while the steady wind correction should be bled off as the airplane approaches touchdown.

It is recognized that the actual wind encountered on the approach may vary from that reported by the tower due to terrain or climactic phenomenon. However, unless actual conditions are known, i.e., reported windshears or known terrain induced turbulence areas, it can be considered reasonable for convenience of operation and to avoid additional cockpit workload to adjust the approach speed by the '1/2 steady headwind component plus gust' values as reported by the tower.'

Using the additions recommended in the FCTM and the wind and gust values reported in the ATIS broadcast (Para 1.7.5) would have resulted in calculated increments of 3 kt for steady headwind plus 18 kt for gust, which exceeds the recommended limit of 20 kt. Thus the target approach speed based on ATIS winds should have been 161 kt. The commander elected to use an increment of 12 kt because, as he later stated, he thought it prudent not to add too much to the V_{REF} of 141 kt.

The retention of adequate flying speed is a pre-requisite for a safe landing. Therefore, although the commander's desire not to arrive too fast was natural, the weather conditions were such that precautions against turbulent gusts and windshear should have taken temporary precedence over stopping considerations. In the event, the commander flew much of the approach at a higher speed than he had earlier intended and the airspeed did not decay below V_{REF}, even after losing 34 kt during the windshear encounter. Thus, although deviation by the commander in calculating target approach speed was not a causal factor in this accident, the fact remained that he did not comply with recommended procedures.

2.6.1.2 Go around procedures

The commander said that he told the co-pilot that in the event of any problems he would initiate standard go-around and missed approach procedures. Because there are important differences between a go-around from low altitude due to windshear and a go-around for any other reason, this was a less than comprehensive briefing for an approach in conditions of known windshear. The go-around procedure which was applicable to a GPWS "WINDSHEAR" audio warning is known as a terrain avoidance manoeuvre. It differs from a normal go-around in the need for maximum thrust, the retention of gear and flap positions, the potential to trade airspeed for height, and the possibility of stick shaker activation. These are fundamental differences which must be appreciated, especially by the non-handling pilot whose job it is to ensure that there are no omissions if the manoeuvre is implemented.

The manoeuvre, the flight conditions which prompted it, and the need for pilots to memorise it were described in detail on page 03.18.04 of Volume 1 of the Operations Manual. The itemised actions of the handling and the non-handling pilot were surrounded by prominent black lines forming a box. This 'boxing' of all or part of a non-normal procedure conveys to aircrew the need to memorise the items inside the box. Such 'boxed items' are given this status because they address emergencies which require immediate action.

It may be argued that because the terrain avoidance manoeuvre was a 'boxed item', both pilots should have known the procedure without any need for review. On the other hand the co-pilot, despite his age, had very little experience of jet aircraft handling and a thorough briefing on the situations which require a terrain avoidance manoeuvre would have been appropriate. A review of the terrain avoidance manoeuvre ought to have been prompted by the 'GO AROUND PROCEDURE' item on the approach briefing checklist. The commander's oversight was not a critical lapse in airmanship but it was indicative of a lack of appreciation of the co-pilot's role in the overall safety of the flight. Furthermore, it was a surprising lapse from a recently appointed training captain.

Unlike most non-normal procedures, those related to GPWS warnings were not contained in the 'CHECKLIST' section of the Operations Manual but other 'boxed items' were included. The QRH carried on the flight deck of B-165 was a reprint of this section of the Operations Manual. It too omitted the procedures appropriate to GPWS warnings. When learning or revising memorised procedures, or reviewing them in flight, most pilots use the QRH as a summary of those procedures.

Clearly it would be inappropriate for any pilot to consult the QRH before responding to a GPWS warning but similar logic applies to other serious emergencies which are boxed items. Therefore, to assist pilots in learning and revising memorised drills, and to standardise the status of all drills requiring immediate action, it was recommended to the Boeing Airplane Company that they should include GPWS 'boxed item' procedure steps in the airplane QRH.

2.6.1.3 **GPWS glideslope inhibit**

There were no instructions in China Airline's SOPs or Flight Handbook about suppression of the GPWS aural 'GLIDESLOPE' warning before commencing the finals turn. The ability to suppress the warning deliberately was documented in chapter 22 of volume II of the Operations Manual but there was no reminder to the pilots to do so in their airfield or route briefing material. Moreover, the commander did not brief the co-pilot to inhibit the system before turning finals and the co-pilot did not use his initiative to do so, even after the second and third aural warnings.

From other evidence, it would appear that the "GLIDESLOPE" warning was routinely ignored by many of the airline's pilots whenever they approached runway 13 at HKIA. It may be that because they were used to hearing voice alerts from the GPWS around finals, the pilots of flight 605 did not register the "WINDSHEAR" warning which immediately followed the first "GLIDESLOPE" warning. Alternatively, the possibility that the warning was registered but temporarily disregarded was identified by the aviation psychologist and the likelihood of this explanation is reinforced by the abnormal stress experienced by the pilots at that time.

The psychologist agreed that the best way of dealing with foreseeable problems was to devise procedures to identify the problems and deal with them without the need for problem solving during critical stages of flight. Therefore, it was recommended to China Airlines that they include a reminder in their Flight Handbook to inhibit the GPWS glideslope mode before commencing the finals turn during instrument approaches to runway 13 at HKIA.

2.6.2 The landing briefing

During his approach briefing the commander did not discuss with or announce to the co-pilot his intentions for employing autobrakes or reverse thrust after landing. This omission probably occurred because there was no mention of landing on the company briefing card. Moreover, since there was no mention in the FCTM, the Operations Manual or the company SOPs about items relevant to the landing during approach briefings, this omission from the card was, to some extent, understandable for these documents were the basis for China Airline's flight crew orders and instructions.

The landing roll procedure in the Operations Manual required the handling pilot to perform all the required actions after touchdown. The duties of the non-handling pilot are to monitor the actions of the handling pilot, to call out any system abnormalities (but not to rectify them), and to announce '60 KNOTS' during the rollout. Thus it may be argued that the non-handling pilot did not need to be briefed. However, had the commander discussed his intentions with the co-pilot, the latter would have been better placed to identify any abnormalities and he would have had the opportunity to query the commander's intentions and perhaps persuade him to modify them. The co-pilot was denied this opportunity but it seems apparent from his subsequent actions that he was expected to hold the control wheel after landing. The commander stated that he instructed him to do so but the instruction was not recorded on the CVR; therefore it was probably given during the approach briefing. If so, it follows that the commander briefed the co-pilot only on the actions he wanted from him; the commander did not reciprocate by telling the co-pilot what actions to expect from his captain. By keeping the co-pilot ill-informed about the landing procedure, and by giving him a non-standard duty to perform, the commander diminished the co-pilot's ability to perform his primary function. These were errors of omission and commission which were causal factors in the accident which followed.

Given that every approach should end in either a go-around or a landing, and that most terminate in a successful landing, it seems inappropriate that the content of an approach briefing should include procedures pertinent to a go-around but not to landing. Whilst it is accepted that the Boeing furnished manuals are written in a form and style that is acceptable to the majority of customer airlines, the omission could be addressed as follows:

a. The Boeing Company should consider including items pertinent to the landing (flap selection, autobrake setting, use of reverse thrust) in the approach briefing section of the 747-400 Flight Crew Training Manual.

b. China Airlines should consider adding 'landing roll procedures' to its approach briefing card for 747-400.

2.6.3 Autobrake setting

The FCTM stated:

'It is strongly recommended that the autobrake system be used in preference to manual braking whenever runway limited, landing on slippery runways or landing in a crosswind, or in other conditions of increased workload such as engine inoperative or low weather.'

The FCTM advised that autobrake settings 1 or 2 would provide moderate deceleration suitable for all routine operations and that settings 3 or 4 should be used for wet or slippery runways or whenever landing rollout distance was limited. China Airlines had no written company procedures for using autobrake but setting 2 was routinely used by its pilots at HKIA. In his report, the psychologist wrote:

'The fact that the pilot selected his habitual setting (of two) for the autobrake system suggests, albeit weakly, that he regarded this system as something that could look after itself with only the minimum of intervention from himself.'

Several factors requiring the use of setting 3 or 4 existed; the runway would be wet and perhaps slippery, there would be a limiting crosswind but little headwind component on the rollout and there was a probability of touching down fast beyond the ideal point defined by the PAPIs. Moreover, runway 13, although not performance limiting in respect of landing weight, is particularly unforgiving in that it is surrounded by water.

Through the application of common sense to knowledge and experience, the commander should have selected autobrake setting 3 or 4. That he did not do so may have reflected a lack of appreciation of the performance of the system. The Operations Manual made clear that autobrake is designed to achieve a given deceleration rate irrespective of reverse thrust or speedbrake operation. In practice, when reverse thrust and speedbrakes deploy, their contribution to the deceleration force normally offloads rather than adds to the effect of wheel braking. Consequently, given the touchdown speed, it is possible to determine a nominal landing rollout distance for each autobrake setting; the data are included in a graph within section 4.13 of the Airplane Flight Manual. The graph shows that in conditions prevailing at the time of the accident, for a touchdown ground speed of 160 kt, the rollout distances for autobrake settings 2, 3 and 4 would have been 2,350, 2,100 and 1,720 metres respectively. Since the landing distance available on runway 13 is 2786 m and the ideal touchdown point is 300 metres from the threshold, there is approximately 2,500 metres of runway in which to stop the aircraft from a perfect touchdown position. In the event, the aircraft touched down beyond the PAPIs with about 2,300 metres of runway remaining. Autobrake 2 might have been just sufficient for turning off at the final exit but the margin for error would have been very slender; a margin which the commander did not determine before landing. Of course, he retained the option of increasing braking pressure with his feet to reduce the rollout distance but this option depended on him identifying the need to do so before it was too late.

There can be no doubt that setting 3 was more appropriate and setting 4 would have been suitable for the conditions. However, although there was a simplified guide to stopping distances with automatic wheelbrakes in the Operation Manual Volume 3, the crew did not refer to it. Had they done so, they would have appreciated that settings 3 or 4 were more appropriate for the prevailing conditions.

2.6.4 Events during the approach

2.6.4.1 Speed display anomaly

The absence of reference speed on the PFDs after the commander disengaged the autopilot and autothrust was a minor annoyance which was quickly corrected by his co-pilot. The temporary problem did not affect the flight and should not be associated with any subsequent events.

2.6.4.2 Response to the amber windshear alert

Throughout the approach airspeed was oscillating by as much as 10 kt/sec in turbulence. It would have taken at least 3 seconds to identify a significant trend and so maintaining a stable target speed of 153 kt in these conditions would have been extremely difficult. Just before the amber alert appeared, when the airspeed was increasing rapidly towards 170 kt, the co-pilot called "PLUS 10" and the commander reduced thrust. Both pilots then became aware of the warning on their PFDs and the airspeed peaked at 179 kt (26 kt above target).

A few seconds after the amber alert the commander increased thrust and the airspeed stabilised about a mean of some 160 kt. His response to the amber alert was reasonable and the high sink rate did not start to develop until about 10 to 12 seconds later. The co-pilot, on the other hand, said nothing for 23 seconds after the commander alerted him to the amber alert. Whether or not he was ordered to do so, the co-pilot should have been paying special attention to airspeed and descent rate. The descent rate started to increase five seconds before the subsequent audio alert and it exceeded 1000 fpm two seconds before it, but still the co-pilot remained silent. Either he was not monitoring descent rate or he observed it without appreciating the trend. Under normal circumstances it might be understandable for a pilot to overlook this trend, but to do so as non-handling pilot after an amber windshear alert indicates a lack of awareness of or confidence in his role.

It is in situations such as low-altitude windshear, where the flightpath can rapidly become dangerous, that the non-handling pilot should be most vigilant. If the non-handling pilot perceives an unsafe trend, it is vital that he or she immediately and clearly states to the handling pilot what is going wrong. For commanders, making such statements to co-pilots is a simple act of exerting their authority. For co-pilots, the act of commenting on a captain's handling is less natural, especially when there is a high 'cockpit authority gradient'. The confidence to do so comes with training, experience and an atmosphere of mutual respect on the flight deck. These aspects will be discussed in detail in later paragraphs.

2.6.4.3 Response to the red windshear warning

The flight data shows that the commander had begun to correct the sink rate by increasing pitch attitude about four seconds before the audio warning sounded but he did not increase thrust until one second before the warning. The contention by both pilots that neither heard the "WINDSHEAR" audio warning is credible given that both were accustomed to hearing nuisance "GLIDESLOPE" warnings after commencing the finals turn. However, both pilots did see the word 'WINDSHEAR' displayed in bold red letters on their PFDs. Notwithstanding the fact that airspeed was close to target, the commander ought immediately to have initiated a terrain avoidance manoeuvre and the co-pilot should have called for such action. The decision to continue the approach was contrary to the Operations Manual, the FCTM, type conversion training, recent simulator training and good airmanship. However, the commander's actions, which he executed in silence, were successful in arresting the rate of descent without reducing airspeed below V_{REF}. The aircraft retained sufficient energy to avoid the ground but, because the pilots had no way of knowing the severity or duration of the shear, this was achieved more by good fortune than by skill, and the aircraft sank from 20 feet above to 70 feet below the 3.1° glidepath in 7 seconds.

The question arises: 'Why did the crew not carry out a terrain avoidance manoeuvre on receipt of the windshear warning?' There are a number of possible reasons. Firstly, the pilots had received numerous warnings to expect windshear on finals. Thus the occurrence of a windshear warning was not totally unexpected and as the psychologist pointed out, the commander would have been expecting some windshear effects as a relatively normal consequence of the approach. Secondly, the commander had recognised the increasing sink rate just before the warning and he had begun to take corrective action; reasonably, he may have decided that his action was sufficient to cope with the sort of windshear he had previously experienced at Hong Kong. Thirdly, both pilots were used to hearing GPWS warnings during the finals turn because they never inhibited the glideslope warning. When the aural warning sequence began, the first word was "GLIDESLOPE" and neither remembered hearing the voice changing to "WINDSHEAR". Fourthly, the aircraft which preceded flight 605 landed successfully and this may have clouded the commander's judgement and encouraged him to 'press on'. Finally, because on final approach the GPWS can issue either 'hard' aural warnings which must be obeyed (eg "PULL UP"), or 'soft' aural warnings which are advisory (eg "GLIDESLOPE"), it is possible that the commander may not have distinguished between the two types.

2.6.4.4 Significance of the windshear encounter

The aviation psychologist (see Appendix 26) considered that although the windshear would have been fairly stressful to many crews, it may not have unduly stressed the commander.

The touchdown was reasonable and there was no obvious relationship between the windshear and subsequent events on the runway. Moreover, both pilots stated that they did not feel any great sense of relief at achieving a safe touchdown. Therefore, although a relationship between the windshear encounter and subsequent events could not be excluded entirely, the windshear encounter was unlikely to have been a primary causal factor in the accident.

2.6.4.5 Lateral gusts

The lateral gusts which struck the aircraft on short finals may have been caused by wind flow patterns around local obstructions. Similar flight path disturbances had been experienced by preceding aircraft and some had executed late go-arounds. Alternatively, the gusts may, like the windshear encounter, have been caused by a transient weather condition. Eye witnesses saw flight 605's flightpath disturbed in roll and yaw by gusts but reported that the aircraft seemed to be less affected than others which preceded it. The flight data showed that large control inputs opposing the gust induced motion had been speedily and correctly applied and to some extent these timely corrections minimised unwanted motion. There were also other large roll and rudder control inputs made to align the aircraft with the runway at a very late stage on finals. Given the general weather conditions and the curved approach, this was neither surprising nor sufficient reason for a late go-around provided that the commander was assured of touching down safely within the touchdown zone. This he achieved. The gentle, wings-level, fully controlled touchdown was a demonstration of his skill, although his technique differed from that recommended in the FCTM. The differences are described in the next paragraph.

2.6.5 Touchdown parameters

Touchdown occurred at 160 kt groundspeed (165 kt mean CAS) approximately 480 metres beyond the displaced threshold for runway 13. Although this was 12 kt faster than intended and 230 metres beyond the ideal touchdown point, it was achieved at a speed close to Boeing's recommended speed of 161 kt (V_{REF}+20) for the wind conditions. Also, it was almost within the 1,000 to 1,500 feet zone (305 to 457 metres) beyond the threshold recommended for the conditions in the FCTM paragraph on crosswind landings. Moreover, according to Boeing's performance data, the aircraft should have had no difficulty in stopping within the 2,300 metres remaining. However, although the FCTM advises that it is not necessary to eliminate the crosswind crab angle prior to touchdown on wet runways, the commander elected to use right rudder to reduce the difference between aircraft and runway headings on touchdown; as a result, without the aircraft's full weight on the tyres, it started to drift slightly downwind towards the right hand side of the runway. The unwanted motion inevitably complicated the commander's handling task at a crucial time and this is indicated on the DFDR trace by the rudder pedal activity. As recommended in the FCTM, the aircraft should have been allowed to touchdown on a heading which was consistent with the aircraft's flight path (i.e. the 'crab' technique) rather than pointing along the runway. Its natural tendency to align itself with the runway could then have been exploited to minimise the commander's workload. Nevertheless, the aircraft did not drift off the runway and neither the pilots nor any of the eye witnesses perceived that it might despite the subsequent roll oscillations. Consequently, for the prevailing conditions, this was an acceptable touchdown which could and should have continued to a safe stop. The touchdown parameters were not a causal factor in this accident.

2.6.6 Landing roll procedure

2.6.6.1 Thrust lever handling

The commander had closed the thrust levers before mainwheel touchdown and the air ground logic changed to ground immediately so there should have been no impediment to him selecting reverse thrust. When asked why he did not do so, the commander said that he was waiting to stabilise the aircraft before selecting reverse thrust.

Regarding actions after landing, the Boeing FCTM stated that, for maximum effectiveness, : *'simultaneously apply braking and reverse thrust. Fly the nose wheel down to the runway smoothly without delay'*, and later *'after touchdown and thrust levers idle, rapidly raise the reverse thrust levers up and back'*. On the subject of crosswind landings, the manual also stated: *'Immediately after touchdown, expeditiously accomplish the landing roll procedure.'* These statements are clear instructions and there was no mention of 'stabilising the aircraft' before selecting reverse thrust. However, 'touchdown' was not defined. In discussion with Boeing it was determined that the company's definition of touchdown was when all the mainwheels were in contact with the runway. It was never intended by Boeing to infer that selection of reverse thrust should be deferred until the nosewheels were in contact with the runway and there was no advice in any of the 747-400 manuals to delay selection of reverse thrust for any other reason. Similarly, there was no such advice in the manuals for other Boeing jets that the commander had flown before the 747-400. To avoid any future misunderstandings, it was recommended to Boeing that the word 'mainwheel' should be inserted before the word 'touchdown' in the appropriate sections of the FCTM.

2.6.6.2 Movement of the thrust levers

Given the commander's high workload, a slight delay in selecting reverse thrust would have been an acceptable consequence of his prioritising his various tasks in the difficult weather conditions and it would not have prejudiced a safe stop. However, the delay was more than slight, and by not selecting reverse thrust, the commander permitted the thrust levers to be advanced after touchdown. Though probably small, the advance was sufficient to trigger automatic responses from the autobrake and speedbrake systems which were appropriate to a rejected landing (taking off instead of stopping after touchdown). The commander had no intention of rejecting the landing and he could not remember how or why the thrust levers were advanced. The co-pilot did not touch them, the commander felt no restrictions or feedback from the autothrottle mechanism and the flight data showed that it remained disconnected. The commander's seat and harness remained locked and he was not knocked forward or sideways by aircraft motions. Moreover, until the roll excursions started, he had no reason to remove his right hand from the forward thrust levers except to move it forwards and downwards to the reverse thrust levers. He was wearing a short sleeved shirt, so he could not have caught the levers with his sleeve as he repositioned his hand.

Thrust lever angle was not recorded by the DFDR and movement of the levers had to be deduced from engine behaviour. The engines accelerated at different rates and No 1 achieved a higher EPR than No 4 which may indicate some asymmetric advancement of the levers. Alternatively, Boeing stated that the asymmetric response of the engines to thrust lever advancement just after touchdown was probably due to the high crosswinds at the time. Strong crosswinds can cause extreme transient flow conditions in the engine inlets which affects the pumping characteristics and stability of the fans.

Nevertheless, whether symmetrically or asymmetrically, all four levers were advanced about two seconds after touchdown and this is unlikely to have been caused by vibration. Therefore, it appears that the commander must inadvertently have advanced the levers after touchdown. In explaining why this may have happened, the psychologist wrote:

'All of us occasionally do things that we do not intend, but we do not usually make completely random actions: we usually intend to do one thing but actually do another. It is therefore tempting to speculate that, in this instance, the captain's intended action immediately after touchdown was to select reverse thrust but that he inadvertently opened the thrust levers instead. Such an explanation is not completely implausible since well-rehearsed behaviours (opening thrust

levers, selecting reverse) need only to be initiated consciously. They are then executed automatically unless they are monitored consciously or unless the desired result is clearly not produced. In this instance, the captain's attention would have had large demands on it and this would have increased the probabilities both that he would activate an inappropriate item of automatic behaviour or motor programme (opening the thrust) even though he made the correct conscious decision (select reverse) and that he would have failed to appreciate this incorrect action for some seconds.'

Given the circumstances and the commander's testimony, the psychologist's explanation for the inadvertent throttle opening appears to be the most likely reason for the commander's inappropriate handling of the thrust levers.

2.6.6.3 The consequences of inadvertent thrust lever movement

The consequences of advancing the levers instead of selecting reverse thrust were serious. Residual forward thrust increased, wheel braking stopped and the speedbrakes were retracted. Neither pilot noticed these very important changes. They did not look at the speedbrake lever and they may not have felt the effect of wheel brakes because brake pressure was being phased in. Also, even at its fully developed level, the deceleration required to satisfy the autobrake 2 schedule would have been little more than the retardation due to aerodynamic forces at 170 kt airspeed.

Thus when the brakes released, they did so gently. At much the same time the speedbrakes retracted smoothly and there would have been no sudden change in deceleration which the crew could have sensed physically rather than visually.

The commander closed the thrust levers again within four seconds of advancing them just as the first roll excursion started. Had he selected reverse thrust at the same time, the speedbrakes would have deployed and retardation would have increased to a level more consistent with a successful stop. The lack of wheelbraking, the 'AUTOBRAKES' EICAS message and the observation of runway exits passing by would usually alert a crew that the aircraft was not decelerating normally; however in this case, both pilots became mentally saturated by roll control difficulties. The commander's recollection that he was waiting to stabilise the aircraft before selecting reverse is not contested. He was in the process of stabilising the aircraft's heading when the co-pilot induced roll excursions which undoubtedly required his intervention. For him, regaining roll control became a higher priority than selecting reverse thrust and his mental processes began to be overtaken by events.

However, the roll excursions started several seconds after the thrust levers were inadvertently advanced. Therefore, the initial delay in selecting reverse thrust could not be attributed to the co-pilot's handling errors, although those errors further delayed its selection. It was the commander's inadvertent deviation from the landing roll procedure, in that he advanced the thrust levers when he should have selected reverse thrust, that was the primary causal factor in this accident.

2.6.6.4 **Roll control handling**

The co-pilot took over the duty of controlling the aircraft in roll from the commander five seconds after touchdown. By taking hold of the control wheel without a specific contemporary instruction to do so, and in the absence of any comment by the commander, the co-pilot demonstrated that the commander expected him to do it. The wheel was already rotated slightly to the left when the co-pilot took hold of it and the commander expected him to keep the wheel in the same position. Instead, the co-pilot immediately applied more left wheel. Moreover, having been corrected verbally and physically by the commander, and having seen the commander restore the aircraft to wings-level, he did it a second time.

The Boeing 747-400 has a relatively narrow main gear track of 11 metres in relation to its wingspan of 65 metres. Like many swept wing aircraft, it has a tendency to roll 'out of wind' after touchdown and so it must still be 'flown' after touchdown, especially in gusty crosswinds. Moreover, on this landing, neither pilot realised that the speedbrakes had retracted and that the wing would have been producing more lift than normal during the landing run. In these conditions it would not be sufficient to place the control wheel in one pre-determined position; the pilot handling the control wheel would have to look outside the cockpit to obtain the required visual references with which to keep the aircraft's wings level.

The co-pilot had no experience of other swept-wing jets and he was unlikely to have acquired an instinctive understanding of their generic handling qualities in strong crosswinds. Furthermore, despite his hours on type, it is unlikely that he would previously have been the handling pilot for landings in limiting crosswinds. Indeed, it is conceivable that these were the most difficult crosswind conditions he had ever witnessed on the Boeing 747-400. On this flight, until the landing, he had not handled the controls and he would have had little or no tactile appreciation of the aircraft's roll response in the gusty crosswind. Consequently, it is possible that he did not appreciate the effect of rotating the wheel to two thirds travel and that he attributed the roll excursions to something other than a mistake by him; this would be consistent with his duplicated error and the subsequent but immediate denial that he had done anything wrong. There are two more potential reasons why the co-pilot applied too much wheel. They are: the possibility that he was attempting to read the EICAS in accordance with his normal non-handling duties; and his previous familiarity with turboprop aircraft where full control wheel into wind is sometimes necessary in a limiting crosswind.

The psychologist explained the human factors behind the co-pilot's roll control behaviour in his report as follows:

'Broadly speaking, humans can operate equipment and exercise skills in either 'open loop' or 'closed loop' ways. Normally, people operate analogue controls that produce analogue responses (when steering a car or maintaining the attitude of an aircraft) in a closed loop way. A given amount

of control input produces an observed degree of system behaviour and this produces a further tailored degree of control input. Control input and system behaviour are thus closely matched. When operating in open loop mode, however, a certain stimulus produces a fixed control response from the operator regardless of its consequences on the system. The loop may be open because the operator is prevented from observing the system response, because he has never learned to observe it, or because he has for some reason developed a rigid pattern of behaviour that he fails to tailor to the situation.'

It would appear that, in this case, at least two of these conditions prevailed. The first officer may not have been giving all of his attention to the control of roll and he had, furthermore, gained a great deal of experience on aircraft types on which full aileron during the landing roll would not have produced sufficient lift differential between the wings to produce significant roll. Thus his experience would have tended to have produced in him a fixed 'open loop' response to crosswind landings that would have comprised applying a considerable amount of aileron with no requirement for monitoring its effects'.

Finally, to some extent, performing simultaneously the normal duties of the non-handling pilot and the abnormal duty of roll control on the runway would have been difficult for any pilot to execute efficiently, for if the non-handling pilot takes over roll control after landing, he has conflicting tasks of looking in to monitor the EICAS display and looking out to keep the wings level. Probably this conflict was partly responsible for the co-pilot's inadequate performance at both tasks. He could not remember whether he was looking inside or outside whilst holding the control column but, whatever the reason for his errors of skill, he should not have been expected or encouraged to control the aircraft in roll after the commander's landing.

2.6.6.5 China Airlines' procedures

There was no mention of the need to exchange roll control between pilots in any of the Boeing manuals; on the other hand, there was no advice or instruction specifically prohibiting the practice which, according to the crew of flight 605, was widespread within China Airlines. Both pilots stated it was a standard procedure within the airline but one which was only invoked if the handling pilot requested it. Neither pilot could recall where this procedure was documented in any of the company manuals but the commander, who was a training captain, stated that it was taught as normal practice during training. In fact, there was no official adoption of or written authorisation for the practice by the airline's senior management. They expected pilots to conform to the procedures specified in the Boeing Operations and Flight Crew Training manuals.

In view of the spread of this non-standard practice, and to prevent a similar occurrence, it was recommended that China Airlines should emphasize to its pilots the dangers of exchanging roll control during landings.

2.6.6.6 **Commander's crosswind landing technique**

The commander stated that he wanted the co-pilot to take the control wheel after touchdown because he needed to move his left hand from the wheel to the nose wheel steering tiller. Again there was no written requirement to do so because the nose wheel steering authority through the rudder pedals is adequate for directional control at the limiting crosswind. After several thousand hours on Boeing 747s the commander should have known this, but it would appear that he, together with other commanders on the airline's 747-400 fleet, had developed a technique for crosswind landings which was significantly different to that published in the Boeing manuals. The technique was unsound because the co-pilot not only lacked the necessary skill and experience to control the aircraft in the prevailing conditions but was prevented from performing his own duties of monitoring rollout progress and proper autobrake operation. Moreover, in failing to relieve the commander of part of his workload he inadvertently added to it. Once the co-pilot had been relieved of the task of roll control, he resumed his normal duties and informed the commander that autobrakes and reverse thrust were not operating. Unfortunately the realisation came too late for the commander to stop the aircraft on the runway. Therefore, although the co-pilot's handling error contributed to the accident process, it was the commander's crosswind landing technique that initiated the train of events which resulted in the over-run.

2.6.6.7 Speedbrake lever monitoring

The landing roll procedure contained in the Normal Procedures section of the Operations Manual states that all the vital actions (ie verifying that the thrust levers are closed, the speedbrake lever moves to UP, selecting reverse thrust, keeping the aircraft centred on the runway, lowering the nose wheel and, if necessary, extending the speedbrakes and applying the wheel brakes) are to be performed by the handling pilot. This places a high workload upon the individual, especially when a manual landing has to be performed in strong crosswind conditions. Indeed, it is difficult to envisage how the handling pilot could monitor speedbrake lever position at the same time as keeping the wings level, selecting reverse thrust and keeping the aircraft centred on the runway. This problem is recognised in the FCTM on page 2-49 which states:

'The PNF should monitor speedbrake extension after touchdown and if auto extension fails, announce 'SPEEDBRAKE''.

The wisdom of this statement is obvious but there was no mention of this responsibility in the Normal Procedures section of the Operations Manual where, apart from sharing responsibility for monitoring rollout progress and autobrake operation, the PNF's duties were confined to calling "60 KNOTS". The discrepancy between the two manuals should be reconciled. It was recommended, therefore, that Boeing should revise the landing roll procedure in the Operations Manual to reflect the instructions in the FCTM.

2.6.6.8 Nose wheel steering

The commander was unable to explain why he wanted to use the nose wheel steering tiller at high speed. The FCTM recognised a directional control problem associated with the combination of reverse thrust, slippery runway and crosswind. On page 2-62 there was an explanatory diagram and paragraph which stated:

'As the airplane starts to weathervane into the wind, the reverse thrust side force component adds to the crosswind component and drifts the airplane to the downwind side of the runway. Main gear tire cornering forces available to counteract this drift will be at a minimum when the antiskid system is operating at maximum braking effectiveness for existing conditions. To correct back to the centreline, reduce reverse thrust to reverse idle and release the brakes. This will minimize the reverse thrust side force component without the requirement to go through a full reverser actuating cycle, and provide the total tire cornering forces for realignment with the runway centreline. Use rudder, steering and differential braking, as required, to prevent over correcting past the runway centreline. When re-established near the runway centreline, apply maximum braking and reverse thrust to stop the airplane.'

As a recently appointed training captain, it is probable that the commander had studied the contents of the FCTM with a more discerning eye for detail than he had earlier employed as a line captain. In re-reading the paragraph and diagram concerning directional control, he may have misunderstood the sentence: *'Use rudder, steering and differential braking, as required, to prevent over correcting past the runway centreline.'* He may have interpreted the phrase to mean that if rudder was insufficient, he should be prepared to use nose wheel steering via the tiller to augment rudder control. This might be the reason for placing his left hand on the nose wheel steering tiller just after touchdown whilst keeping his right hand on the thrust levers. Morover, the commander may not have been the originator of the practice within the airline; that may be why he was unable to explain the reason for it.

Since the rudder pedals are connected to the nose wheel steering mechanism, during the landing roll it is not normally possible to use rudder without nose wheel steering unless the nose wheel steering tiller is restrained. Boeing never intended that pilots should use the nose wheel steering tiller during the early stages of the landing rollout; angled nose wheel tyres tend to skid or scrub on wet surfaces and, on dry surfaces, tiller gearing is too coarse for directional control at high speed. They made this clear in another section of the FCTM about landing factor considerations which stated:

'Rudder pedal steering is sufficient for maintaining directional control during the rollout. In a crosswind, displace aileron into wind sufficient to maintain wings level and aid directional control.'

The inclusion of '*steering*' within the phrase '*use rudder, steering and differential braking, as required*' is an unnecessary duplication which may be misunderstood. Therefore, it was recommended that Boeing should revise the FCTM to clarify the advice relating to crosswind landing technique on slippery runways.

2.6.6.9 **Warnings**

There was no automated reminder to the crew to select reverse thrust nor any warning that the thrust levers were inappropriately positioned despite the situation being recognised as an abnormality by the Central Maintenance Computers. There was an EICAS advisory message about the change in autobrake status but there was no audio or master caution light warning of autobrake disarming or of speedbrake retraction. As to why the pilots did not appreciate that the aircraft was not decelerating properly, the aviation psychologist stated:

'It was not until some 15 seconds after touchdown that the first officer noted the absence of autobraking. This may seem a long period of time to have elapsed without the aircraft slowing and without the crew appreciating it. It is likely, however, that the events already described above were directly responsible for preventing the crew from having sufficient spare capacity to monitor the state of the autobrake system or from realising from direct observation that the aircraft was not slowing.'

This failure of the crew to appreciate the absence of an automatic system that they believed was selected and that should have been operating is a particular example of the *problem sometimes referred to as 'mode awareness' of automatic systems. It is very easy for crews in aircraft in which many functions can be undertaken manually or in a variety of automatic modes to be unaware, for a variety of reasons, of the precise state at any given time of these modes of operation. If the crew members believe that they have set the aircraft up in a particular way, then they may well continue to believe or to assume that the aircraft is behaving in the way they intended.'*

It is therefore possible that, because the crew of flight 605 had selected automatic speedbrake extension and wheelbraking, this resulted in them not monitoring the performance of the automatics after landing. In this respect the pilots of flight 605 were not behaving abnormally; delegation of these tasks to the automatic systems is recommended in the 'Automatic Brakes' and 'Crosswind Landings' sections of the FCTM and the pilots are required only to 'monitor' the automatic systems. But, by accidentally opening the thrust levers after touchdown, the commander triggered responses within the automated systems which were totally contrary to his intentions. Warning of these unwanted changes was not signalled to the pilots because the aircraft's systems designers assumed that forward movement of the thrust levers in these circumstances would always be intentional. They intended that autobrake and speedbrake should be deactivated if the thrust levers were advanced in preparation for a rejected landing, and an unwanted aural warning during an intentional rejected landing would be an unnecessary distraction. But rejecting the landing was not the commander's intention. Had he or any other pilot decided to go-around from the runway, it is reasonable to assume that the thrust levers would have been advanced much further than the 8° ± 1° which deactivated the braking systems. On the other hand, Boeing explained that the aircraft must be reconfigured as soon as a go-around from the runway is initiated, and that the necessary switching must be accomplished as soon as the thrust levers are advanced beyond the idle range.

This accident was the second Boeing 747-400 over-run during 1993. In both cases unwanted forward movement of a thrust lever disarmed the autobrakes and retracted the speedbrakes. Also in both cases, but for different reasons, the landing rollout was extended by unwanted forward thrust. Had the sequence of events which took place in Hong Kong occurred in an earlier model of the Boeing 747, there would have been a third crew member to monitor the systems and pilot actions. It is accepted that most of the tasks performed by the third crewman in the earlier models have been successfully automated in the design of the 747-400, but the lack of any automated monitoring of landing rollout configuration resulted in a disastrous lack of 'mode awareness'. This may also have been a factor in the other Boeing 747-400 overrun accident.

For other critical stages of flight such as take-off and approach, the aircraft has configuration warning systems yet there is no aural or tactile warning to alert the pilots to an unsafe rollout configuration. At the time of the accident, had there been, unmistakable warning(s) that reverse thrust was not engaged, that speedbrakes had retracted, and that autobrakes had disarmed, the pilots might have acted earlier to prevent the accident. Therefore, it is recommended that the certification authorities should consider a requirement for a warning system which would alert pilots to abnormal changes in the landing rollout configuration and retardation systems.

2.6.7 Rejected landing capability

Just as the co-pilot reminded the commander that reverse thrust had yet to be selected, the flight deck was passing exit A10 with about 900 metres of runway remaining. At this point there were two options open to the commander: either to stop, or to reject the landing by applying power and taking off. The commander opted to stop but the question of whether a rejected landing was feasible should be considered to determine whether that option could have averted the accident. The aircraft had been rolling along the runway without being actively retarded for 15 seconds since the disarming of the autobrakes and the airspeed abeam exit A10 was about V_{REF}. During that period the airspeed had decayed at a rate of approximately 1 kt/sec. If the decision to reject had been made at 140 kt by advancing the thrust levers to go-around thrust, the aircraft would not have decelerated by more than about 5 kt and as thrust increased, it would have begun to accelerate. At an average airspeed of 140 kt, the equivalent groundspeed would have been 130 kt and travelling the remaining 900 metres would have taken 13 seconds. The engines would have reached full thrust before the aircraft reached the end of the runway and rotation speed with flaps at the go-around setting of 20 was 119 kt. Therefore, in theory the commander could have rejected the landing successfully. This theory was tested several times in full flight simulators by several pilots using flaps 20 and flaps 30 (ie without moving the flaps) and without changing the pitch trim. If rotation was commenced in sufficient time, the aircraft crossed the end of the runway at more than 150 kt and climbed away regardless of the flap position. The commander had the experience and training required to execute a rejected landing and he should have been able to judge the right moment to begin rotation, ie at the basic V_{REF}. Therefore, a rejected landing immediately after the roll excursions had ceased could have been successful and the accident could have been averted.

2.6.8 Rejected landing technique

The technique for a rejected landing was covered in the FCTM which stated that *'The rejected landing procedure is identical to the go-around procedure.'* In part this advice was sound but there is a significant difference between the two situations. In the go-around, the aircraft will normally be flying at a speed greater than V_{REF} and the engines will be running at greater than flight idle speed. In the rejected landing, the aircraft's weight will be on its landing gear, its speed will probably be below V_{REF} and its engines may be at ground idle thrust. Consequently, having advanced the thrust levers to the go-around position, the pilot needs to know at what speed relative to V_{REF} for landing he should begin rotation for take-off, and whether or not he can safely begin rotation before the engines have reached the go around thrust rating; he also needs to know what pitch guidance (if any) is available if the TO/GA switch is operated as part of the rejected landing procedure. None of these aspects are covered in either the Operations Manual or FCTM. Therefore, it was recommended to the Boeing Airplane Company that FCTM guidance on the technique for a rejected landing should be expanded to include the conditions for commencing rotation on the runway.

2.6.9 **The decision to stop**

The argument that a rejected landing could have been successfully carried out is hypothetical. The commander did not consider the option; he decided to stop because, at the time the co-pilot called for reverse thrust, neither he nor the co-pilot had perceived that the aircraft was unlikely to stop in the remaining distance. By the words spoken softly to himself, the co-pilot indicated that he realised there was insufficient runway remaining in which to stop when he was about 850 m from the end. The same realisation came to the commander a little later as he passed the high speed exit at A11 some 640 m from the end; by this time reverse thrust had been selected. Because it takes two seconds for the reversers to translate to the forward thrust position, and several more seconds to develop significant forward thrust, the opportunity to reject the landing had passed.

2.6.10 **Visibility from the flight deck**

When asked how they judged distance remaining during a landing on runway 13, both pilots stated that they used the exits as reference points. The commander stated that he normally read the signs at each exit whereas the co-pilot used the rapid exit at A11 as his main reference; he also used speed in relation to touchdown position to judge the aircraft's progress. However, during the accident landing, neither pilot recalled seeing the runway lights and neither saw the end of the runway before the decision to stop had been irrevocably taken. The reasons for their lack of situational awareness must be examined.

There were only two ways of judging the amount of runway remaining: either by sensing the amount of runway already used or by visual cues relating to the distance remaining. The first method is imprecise because intuition and experience are key components but both pilots had probably used it to some extent during previous landings. On this occasion both pilots were distracted from their routine tasks by the alarming roll excursions and temporarily, both may have become so pre-occupied with roll control that most if not all other stimuli, particularly the passage of time, were excluded. Consequently, even though the aircraft had been rolling along the runway, unbraked, for 15 seconds, neither pilot realised that the aircraft had used a great deal of the available runway length during the roll excursions. In this situation, only visual cues of runway remaining would have provided the pilots with the information upon which to decide how hard to brake in order to stop before the end. Therefore, the visual scene from the flight deck was an important element in the pilots' judgement of the landing roll progress.

The moderate to heavy rain would have reduced visibility through the windshields. Although the windscreens and wipers were in excellent condition, rain repellent was not used to augment the wipers, and the clarity of the view ahead would have been varying with wiper blade motion. Secondly, there would have been little contrast between the grey, cloud-laden sky; the wet, predominantly grey runway; and the sea, which would also have acquired a greyish tint in the strong wind conditions. Thirdly, the landing rollout was towards sea and away from the airport infrastructure; thus there were no objects near the end of the runway with sufficient vertical extent to judge closing speed. Fourthly, although the red runway-end lights were on and the centreline lights changed colour at 900 metres and 300 metres from the end, it was daylight, the conspicuity of the lights may have been low, and rain on the windscreen would have diffused the pattern and spacing of the lights. Finally, along runway 13 there were few physical distance remaining cues apart from the painted marks on the runway, and the taxiway exits which were all on the left hand side. There were no features on the co-pilot's side of the runway.

As the airport diagram at Appendix 9 shows, the touchdown zone for runway 13 is abeam the end of the apron complex. Thereafter, before the rapid exit taxiway at A11, all the exits are essentially identical and evenly spaced. Given the combined effects of distorted vision, low contrast, and few visual cues upon which to judge closure rate or distance to go, it is not surprising that the pilots were unaware of their predicament until they saw the rapid exit at A11. It was the only feature on the promontory which was sufficiently conspicuous to be readily identifiable in the prevailing weather conditions.

In benign weather conditions there would be no difficulty in judging the amount of runway remaining because the minimum visibility required for making an approach is 3200m, which is almost equal to the length of the runway. Take-off is permitted in lower visibilities but a decision to reject a take-off is less critical than a decision to reject a landing because the decision speed is pre-determined and takes into account the prevailing weather conditions. In flight, however, when it is raining, the visibility on the ground may be quite different to the visibility from the flight deck, particularly in a heavy passing squall of the type that was prevalent on the day of the accident. Some conspicuous visual aids to indicate runway distance remaining, to enable pilots to monitor progress, would enhance landing safety on runway 13. It was therefore recommended that the Hong Kong International Airport authorities consider providing prominent 'distance-to-go' visual aids on runway 13.

2.6.11 Stopping performance

Appendix 23 shows, once the wheel brakes had been fully applied and reverse thrust reached its peak, the retardation force was generally greater than 0.3g until the aircraft was less than 5 seconds from the end of the runway. Before this point there were temporary reductions to as low as 0.15g but the general effectiveness of the brakes and the condition of the tyres eliminated aquaplaning or defective anti-skid units as causal factors. The friction survey showed that the average friction reading over the wet asphalt was only marginally below the design objective for a new runway and well above the maintenance planning criterion. Therefore, contamination on the runway was not responsible for the reduction in braking action.

It is difficult to quantify the reduction in retardation which arose because appreciably less than maximum reverse thrust was employed, but stopping performance would have been improved by using maximum in a situation where every contribution counted. Neither pilot noticed the shortfall in engine EPR or RPM but under the circumstances this is not surprising.

Calculations showed that the first area of reduced braking effectiveness was between 260 and 200 metres from the end of the runway. This region corresponded to the white painted 'piano keys' where the friction reading determined by the surveyor was very low. If, however, the white painted areas had retained the same friction coefficient as the remainder of the runway, calculations indicated that the speed at the end of the runway would have been reduced by only 6 knots, which would not have affected the outcome. The second area where the retardation was less than 0.3g was in the final 91metres of concrete before the end of the runway. The reduction could not have been caused by the surface quality of the concrete because the survey friction reading there exceeded that of the asphalt. Other factors which may have influenced the reduction were cancellation of reverse thrust, retraction of the speedbrakes and the change in heading to the left which all occurred within the last 100 metres. The loss of braking from the reverse thrust and speedbrakes would not have been great because the average airspeed was less than 60 kt but the effect of the attempt to turn left, indicated by the transverse cuts on the nose wheel tyres and the rudder pedal input would have been more serious. The marks on the runway showed that in the final moments of the ground roll, the aircraft was to some extent sliding sideways because hard braking and hard turning were being demanded simultaneously. In these conditions the tyres cannot produce full stopping and full cornering forces; indeed, if the wheels lock, there will be no cornering force. The wheels did not lock but the attempt to turn inevitably reduced the braking effectiveness. To have stopped in the final 100 metres would have required a retardation rate of 0.34g which is about the average rate achieved when all the retardation aids were used on the asphalt.

When questioned as to the intent behind the attempt to initiate the left turn, the pilots gave different answers. The co-pilot thought that the commander was attempting to take the final runway exit (A12) while the commander answered that he was attempting to avoid the approach lights if an overrun occurred; the hard braking and hard turning referred to above (followed by stowing of speedbrakes and cancelling of reverse thrust) were more consistent with the co-pilot's interpretation of events.

On the other hand, if when he first perceived that the remaining runway distance was marginal, the commander had decided to maintain full wheel braking, full speedbrake, maximum reverse thrust and runway heading until the aircraft stopped, the aircraft would have slowed more rapidly. He might then have judged that the aircraft would indeed stop and there would have been no need for a turn. Calculations showed that once the 'piano keys' had been crossed, a steady deceleration in the order of 0.31g would have been sufficient to stop the aircraft on land. Given the enhanced friction surface of the concrete plus the good condition of the brakes and tyres, and the earlier retardation of 0.35 to 0.4g, this level of retardation should have been achievable. Therefore if, when the call for reverse thrust was uttered by the co-pilot, the commander had deployed fully and maintained all the stopping aids until the aircraft came to rest, the aircraft could have remained on the runway.

2.6.12 **Evacuation procedure**

The crew responded quickly in executing the evacuation. Although a few deviations from company procedures were observed, the evacuation was generally orderly and under control. Given the unprepared ditching and the sudden occurrence of the accident, the deviations, which included conducting ditching checks from memory instead of using a check list, activating the passenger oxygen system when there is no requirement and door opening by male attendants instead of the assigned crew, were understandable. Except for some difficulty in controlling the carriage of personal belongings by passengers, no major problem was experienced. Some female attendants, however, commented that their uniforms were not suitable for evacuation as they caused restriction to movements.

2.6.13 **Flight crew's health**

The crew of flight 605 were uninjured and no medical examination was offered or arranged by China Airlines or the Hong Kong authorities after the accident. Although a medical examination was not required or enforceable under Hong Kong aviation legislation, a medical examination would have been in the crew's interest to ensure that they were well enough to withstand the additional stress of interviews by journalists and investigators. Moreover, early and voluntary examination could have eliminated temporary influences such as drugs, intoxicants, food poisoning or environmental contaminants as causal factors. It was recommended, therefore, to China Airlines and to the Hong Kong authorities that flight crews involved in an accident should be offered a medical examination as soon as practicable.

2.6.14 Co-pilot's experience

Before being appointed to the Boeing 747-400 fleet, the co-pilot had not acquired handling experience in other large aircraft, swept wing aircraft or turbofan powered aircraft; he had transitioned from the right hand seat of a light twin turbo-prop directly to the 747-400. The difference in complexity and handling qualities between light turboprops and the 747 is very marked and training alone, however thorough, cannot compensate fully for a lack of experience on aircraft with comparable features. This is especially true on aircraft which are used primarily for long-distance flights. During his 1409 hours on type, the co-pilot is unlikely to have experienced many landings in strong crosswinds.

It is accepted that every airline pilot has to start somewhere in order to gain experience. However, the challenge involved in coping with the additional inertia, size, markedly different handling qualities and complexity of the 747-400 in a two man crew environment was probably too much for the co-pilot despite his mature years. The

Boeing 747-400 Operations Manual recognised the need for experience in its preface which stated:

'This manual is written under the assumption that the user has had previous multi-engine jet aircraft experience and is familiar with basic jet aircraft systems and basic pilot technique common to aircraft of this type. Therefore, the Operations Manual does not contain basic flight information that is considered to be prerequisite training.'

Few major airlines would have appointed a co-pilot without jet airline experience directly to the 747-400 fleet. If the co-pilot had acquired a broader knowledge of jet aircraft operations, he would have been better able to play an effective part in the decision making process and the commander might have shared more decisions with him. He might also have been more prepared to speak out during the windshear encounter. Therefore, it was recommended to China Airlines that they review company policy for co-pilot qualifications on their 747-400 fleet.

2.7 Cockpit Resource Management

Cockpit Resource Management (CRM) is a difficult concept to define succinctly, but its basic principles are concerned with effective coordination and decision making within a group. Inter-crew monitoring and the integrated crew concept have become the norm in airline transport operations. Another accident report described the modern role of the co-pilot as follows:

'The second-in-command is an integral part of the operational control system in flight, a fail-safe factor, and as such has a share of the duty and responsibility to assure that the flight is operated safely. Therefore, the second-in-command should not passively condone an operation of the aircraft

which in his opinion is dangerous, or which might compromise safety. He should affirmatively advise the captain whenever in his judgement safety of the flight is in jeopardy."

'Affirmative advice' may be very difficult for a co-pilot to issue when there is a marked difference in status between the two pilots. This difference may be expressed as a steep 'cockpit authority gradient' yet detailed strategies for dealing with it may not always be included in CRM training. It was not practicable for the investigation team to audit the operator's CRM training but it was known that the management of China Airlines had perceived the need for such training and had purchased the expertise from a well respected North American company. Following CRM training for its senior pilots, the airline reverted to 'in-house' CRM training conducted by those pilots.

With regard to the operation of the aircraft in accordance with the basic principles of CRM, areas of unsatisfactory performance were apparent. Perhaps the most obvious area of concern was the large 'cockpit authority gradient' identified by the psychologist and other members of the investigation team. This gradient may well have been the underlying factor behind various other CRM shortfalls. The gradient is evident in the almost total absence of dialogue between the two pilots on the CVR recording and in the way that the co-pilot often begins or ends his responses to the commander with the word "Sir". To some extent, because of his inexperience, the co-pilot's role on the flight deck was diminished to that of being a pilot's assistant rather than a member of a crew, and that may be why the commander passively restricted the co-pilot's role largely to one of reading checklists and acknowledging ATC instructions.

The commander's unsatisfactory attitude towards the safety and monitoring role of the co-pilot is evident in his total lack of consultation or discussion with him about what should be their (and not just his) plans of action for coping with bad weather, windshear, and a difficult crosswind landing. At the very least, the commander should have shared his thoughts with the co-pilot and sought his suggestions or comments before arriving at a firm decision or plan of action. In so doing, there would have been no need for the co-pilot to challenge or argue with him, and no need for the commander to admit it openly if the co-pilot's plans were better than his own initial thoughts. On the other hand, the co-pilot should not have been afraid to ask the commander about his plans for coping with the rough weather. To some extent, the co-pilot's lack of assertiveness may be attributed to his inexperience but appropriate training and the right working atmosphere on the flight deck could have given him the confidence to ask the commander what he intended to do.

That both pilots seemed to ignore some of the basic principles of CRM is insufficient justification for criticising China Airlines' CRM training program, and no criticism of it is intended. Nevertheless, it is recommended that China Airlines should review its CRM training program to ensure that strategies for dealing with a marked difference in status between the members of a flight crew are effectively taught and understood.

2.8 Procedures and standardisation

2.8.1 Procedures

China Airlines expected its pilots to conform to the procedures described in the Boeing Operations and Flight Training Manuals. The contribution made by the airline's management to the regulations which its crews were supposed to follow was small: one flight handbook and 11 small pages of SOPs. The three-volume Boeing Operations Manual fulfilled its purpose in that it provided the crew with the necessary operating limitations, procedures, performance and systems information to operate the aircraft. However, although Volume 1 contained the detailed procedures, there was no mention of handling techniques; these aspects were covered in the FCTM.

The introduction section of the FCTM stated:

'The Flight Crew Training Manual provides information and recommendations on maneuvers and techniques.'

Qualifying statements were contained in the preface of each section emphasising that the manual was a basis for standardisation and crew coordination. However, China Airlines appeared to assume that it contained almost all the procedures and techniques required for sophisticated, efficient and safe operation. But, because it was never intended to be more than a guide to learning how to fly and operate the aircraft in the Boeing style, the FCTM carried on board the aircraft lacked the detailed instructions which individual airlines often provide to their flight crews regarding company operating policy. China Airlines' flight handbook and the 11 pages of company SOPs did little to augment the Boeing manuals and the airline's operating policies were, therefore, ill-defined.

On the topic of flight crew procedures the aviation psychologist stated:

'It can be argued that the single most important factor that has made aviation as safe as it is currently, has been the extensive introduction and use of procedures for all aspects of aircraft operations, and especially for the flight deck task. The importance of procedures is to relieve the pilot of all thinking and problem solving for events that can be anticipated. The best way of tackling situations and problems is obviously not best identified when they actually arise, but well beforehand when the appropriate responses or behaviours can be

decided upon and rehearsed. Thus the more detailed and well thought out flight deck procedures are, and the more specific they are to the nature of the operation, the safer the system is likely to be.'

Because, at the time of the accident, China Airlines had not issued '*extensive ..... procedures for all aspects of aircraft operations*', it was recommended that the airline should formulate and publish its own 'Operations Manual' which should contain the detailed procedures authorised by the airline's management.

2.8.2 Standardisation

It was not possible to audit China Airlines' commitment to standardisation but clearly, a number of senior pilots had developed non-standard techniques which were accepted by the junior pilots. Without procedures which were sufficiently comprehensive to cover unusual but foreseeable situations, commanders had to be given freedom to deviate from the generalised procedures in the Boeing manuals when faced with circumstances not covered by them. Most of what went wrong during the approach and landing of CAL605 can be attributed either to a lack of detailed instructions for operating to Hong Kong, or more generally, to deviation from the procedures and techniques described in the Boeing manuals. Indeed, notwithstanding the lack of detailed company operating procedures, the accident could have been avoided if the pilots had known, understood and diligently adhered to the Boeing procedures, for it was the commander's personal technique of exchanging roll control for crosswind landings that was ultimately responsible for the runway overrun.

It was recommended, therefore, to China Airlines that the airline should improve standardisation within its pilot cadre.

3 CONCLUSIONS

3.1 Findings

3.1.1 The aircraft was serviceable in all respects relating to its ability to go-around or land normally from the IGS approach.

3.1.2 The weather conditions were not directly responsible for the runway overrun.

3.1.3 The general weather conditions encountered by CAL605 were very similar to the forecast and observed weather reports made available to the crew before and during the flight.

3.1.4 The aircraft was subjected to peak lateral winds of up to 39 kt between 100 and 50 feet height on final approach.

3.1.5 The windshear encountered at the beginning of the finals turn was different to the windshear predicted in the AIP and by the airport's windshear detection system.

3.1.6 The commander deviated from the recommended procedure for determining final approach speed.

3.1.7 During his approach briefing to the co-pilot, the commander should have reviewed the flight crew actions appropriate to a GPWS warning of windshear.

3.1.8 The absence of any mention of autobrake or reverse thrust during the approach briefing made it unlikely that the co-pilot could contribute to or modify the commander's plan for decelerating the aircraft on the runway.

3.1.9 The temporary speed display anomaly on final approach did not affect the flight and should not be associated with any subsequent events.

3.1.10 The co-pilot's apparent lack of response to events following the windshear alerts indicated a lack of awareness.

3.1.11 Having identified a red windshear warning, the commander ought immediately to have initiated a terrain avoidance manoeuvre and the co-pilot should have called for such action.

3.1.12 There was no obvious relationship between the windshear encounter and subsequent events on the runway

3.1.13 The touchdown speed and distance beyond the threshold were acceptable for the prevailing conditions.

3.1.14 There was ample time for the commander to select reverse thrust before the roll excursions occurred, which having commenced, subsequently delayed the opportunity to select reverse thrust.

3.1.15 The commander's personal technique of exchanging roll control for crosswind landings was ultimately responsible for the runway overrun.

3.1.16 A rejected landing immediately after the roll excursions had ceased could have averted the accident.

3.1.17 The visual scene from the flight deck may have affected the pilots' judgement of the landing roll progress.

3.1.18 By the time the commander perceived that the aircraft might not stop within the remaining runway, the opportunity to reject the landing had passed.

3.1.19 The large quantities of rubber contaminant on the runway did not result in an unacceptable reduction in braking action.

3.1.20 If, when the call for reverse thrust was made by the co-pilot, the commander had deployed fully and maintained all the stopping aids until the aircraft came to rest, the aircraft could have remained on the runway.

3.1.21 China Airlines flight handbook and company SOPs did little to augment the Boeing manuals which it had adopted.

3.1.22 Little damage was caused to the aircraft cabin except the main deck first class section where some floor panels and support structure for the overhead luggage bins failed.

3.1.23 Damage in the first class cabin was caused by body deformation resulting from impact of the lower nose section with water and not by inertia loads due to deceleration.

3.1.24 All main deck doors except the two overwing doors were opened for evacuation. All slide-rafts inflated automatically as the doors opened, but the slide at door 5R later deflated, possibly due to perforation by a high-heel shoe.

3.1.25 Evacuation was conducted in an orderly manner and all passengers and crew exited the aircraft in about 20 minutes, just prior to entry of water to the rear of the main cabin via doors 5L and 5R.

3.1.26 Vehicles from the airport fire service arrived at the runway end within one minute of the accident and rescue vessels arrived on scene within five miutes. The rescue operation was completed in about 30 minutes.

3.2 Causal factors

3.2.1 The commander deviated from the normal landing roll procedure in that he inadvertently advanced the thrust levers when he should have selected reverse thrust.

3.2.2 The commander diminished the co-pilot's ability to monitor rollout progress and proper autobrake operation by instructing him to perform a non-standard duty and by keeping him ill-informed about his own intentions.

3.2.3 The co-pilot lacked the necessary skill and experience to control the aircraft during the landing rollout in strong, gusty crosswind conditions.

3.2.4 The absence of a clearly defined crosswind landing technique in China Airline's Operations Manual deprived the pilots of adequate guidance on operations in difficult weather conditions.

4. RECOMMENDATIONS

As a result of the investigation, the following recommendations are made:

4.1 The Hong Kong Civil Aviation Department should ensure that the ATIS broadcast is updated every time a weather report is received from the Airport Meteorological Office. (para 2.4.3)
(Note: This recommendation has been implemented.)

4.2 The Hong Kong International Airport authorities should re-paint the white runway markings with a more suitable paint. (para 2.5.2)
(Note: This recommendation has been implemented.)

4.3 The Boeing Airplane Company should include 'boxed item' procedure steps for GPWS 'WINDSHEAR' warnings in the airplane QRH. (para 2.6.1.2)

4.4 China Airlines should include a reminder in their Flight Handbook to inhibit the GPWS glideslope mode before commencing the finals turn following IGS approaches to runway 13 at HKIA. (para 2.6.1.3)

4.5 The Boeing Company should consider including items relevant to the landing in the approach briefing section of the 747-400 Flight Crew Training Manual. (para 2.6.2)

4.6 China Airlines should consider adding 'landing roll procedures' to its approach briefing card for the 747-400. (para 2.6.2)

4.7 The Boeing Airplane Company should revise the wording regarding selection of reverse thrust in its Flight Crew Training Manual (para 2.6.6.1).

4.8 China Airlines should emphasize to its pilots the dangers of exchanging roll control during crosswind landings. (para 2.6.6.5)

4.9 The Boeing Airplane Company should revise the landing roll procedure in the 747-400 Operations Manual to reflect the instructions in the Boeing Flight Crew Training Manual. (para 2.6.6.7)
(Note : This recommendation is being implemented.)

4.10 The Boeing Airplane Company should revise the 747-400 Flight Crew Training Manual to clarify the advice relating to crosswind landing technique on slippery runways. (para 2.6.6.8)
(Note : This recommendation is being implemented.)

4.11 The certification authorities should consider the provision of a configuration warning to alert pilots to abnormal changes in the landing roll configuration (para 2.6.6.9).

4.12 The Boeing Airplane Company should expand the guidance in its Flight Crew Training Manual on the technique for a rejected landing (Para 2.6.8).
(Note : This recommendation is being implemented.)

4.13 The HKIA authorities should consider providing prominent 'distance-to-go' visual aids on runway 13 (para 2.6.10).
(Note : This recommendation will be implemented.)

4.14 China Airlines and the Hong Kong Civil Aviation Department should ensure that flight crews involved in an accident are offered a medical examination as soon as practicable. (para 2.6.13)
(Note : This recommendation will be implemented by the Hong Kong Civil Aviation Department.)

4.15 China Airlines should review its policy for co-pilot qualifications on the airline's 747-400 fleet. (para 2.6.14)

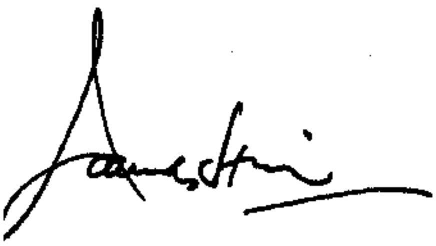
4.16 China Airlines should review its CRM training program to ensure that strategies for dealing with a marked difference in status between the members of a flight crew are effectively taught and understood. (para 2.7)

4.17 China airlines should formulate and publish its own 'Operations Manual' which should contain the detailed procedures authorised by the airline's management. (para 2.8.1)

4.18 China Airlines should improve standardisation within its pilot cadre. (para 2.8.2)

These recommendations are addressed to the regulatory authority of the State having responsibility for the matters with which the recommendation is concerned. It is for that authority to decide whether and what action is taken.

(The invaluable contribution of the UK AAIB inspectors is gratefully acknowledged.)



James C.S. HUI
Inspector of Accidents
Accident Investigation Division
Civil Aviation Department
Hong Kong

APPENDICES

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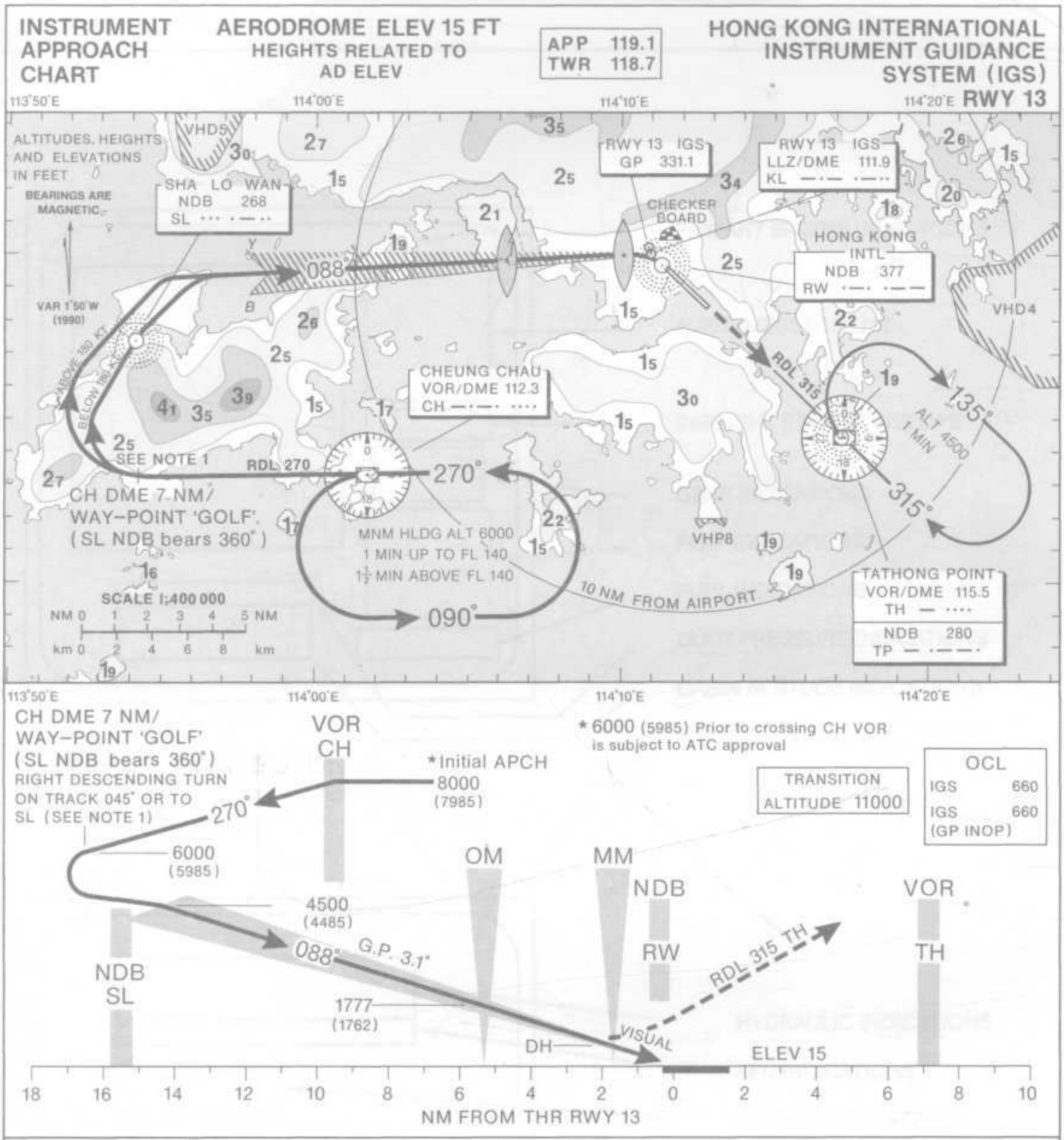
HONG KONG IGS
INSTRUMENT APPROACH CHART



MISSED APPROACH: Continue on the IGS LLZ, climbing to 4 500 ft, at the MM (or 2.2 NM from 'KL' DME if MM is unserviceable), turn right to intercept and establish on 'TH' VOR radial 315 and join the 'TH' holding pattern or proceed as directed by ATC. Or, if 'TH' VOR is not available, continue on the IGS LLZ, climbing to 4 500 ft; at the MM (or 2.2 NM from 'KL' DME if MM is unserviceable), turn right to track through 'RW' NDB on 130°M and join the 'TP' holding pattern or proceed as directed by ATC.

Missed approach turn is based on 15° bank, 1.5° per second rate of turn and an average speed of 180 kt whilst turning.

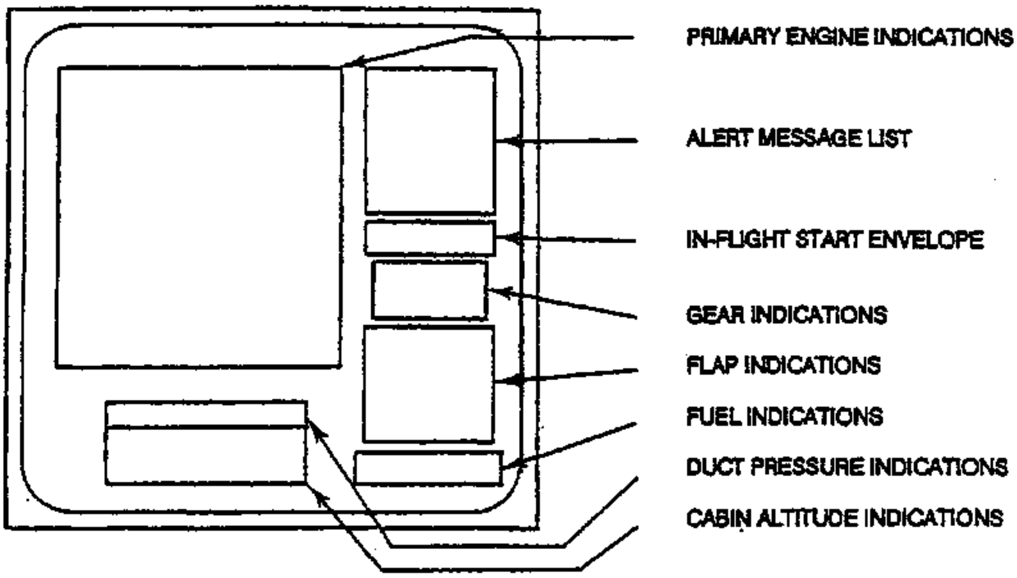
WARNING

Missed approach is mandatory by the MM if visual flight is not achieved by this point. In carrying out the missed approach procedure, the right turn must be made at the MM (2.2 NM from 'KL' DME if MM is unserviceable) as any early or late turn will result in loss of terrain clearance.
After passing the MM, flight path indications must be ignored.

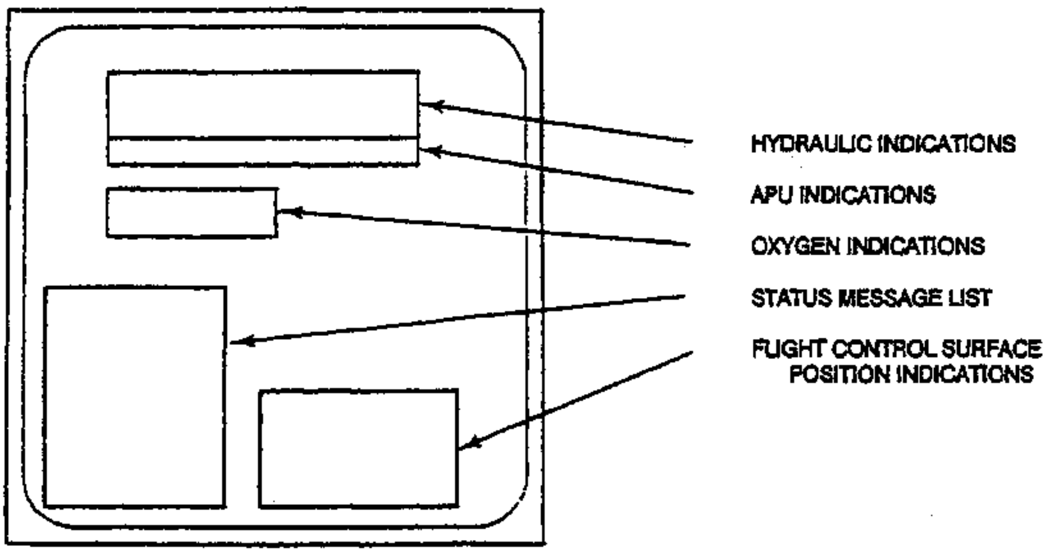
NOTE 1 At 'CH' DME 7 NM ('SL' NDB bears 360°) further descend to 4 500 ft and:–
- (i) turn right to make good a track of 045° M to intercept the LLZ; or
- (ii) aircraft flying at less than 180 kt IAS should turn right to 'SL' NDB and thence track 045° M to intercept the LLZ.

NOTE 2 With GP inoperative – When established on the LLZ at 4 500 ft and at not greater than 'KL' DME 15 NM (2219.12N 11356.05E) descend to 3 000 ft. At 'KL' DME 9 NM, descend as for a 3° GP to cross the OM at not less than 1 800 ft, then continue descend to decision height.

ENGINE INDICATING AND CREW ALERTING SYSTEM (EICAS)

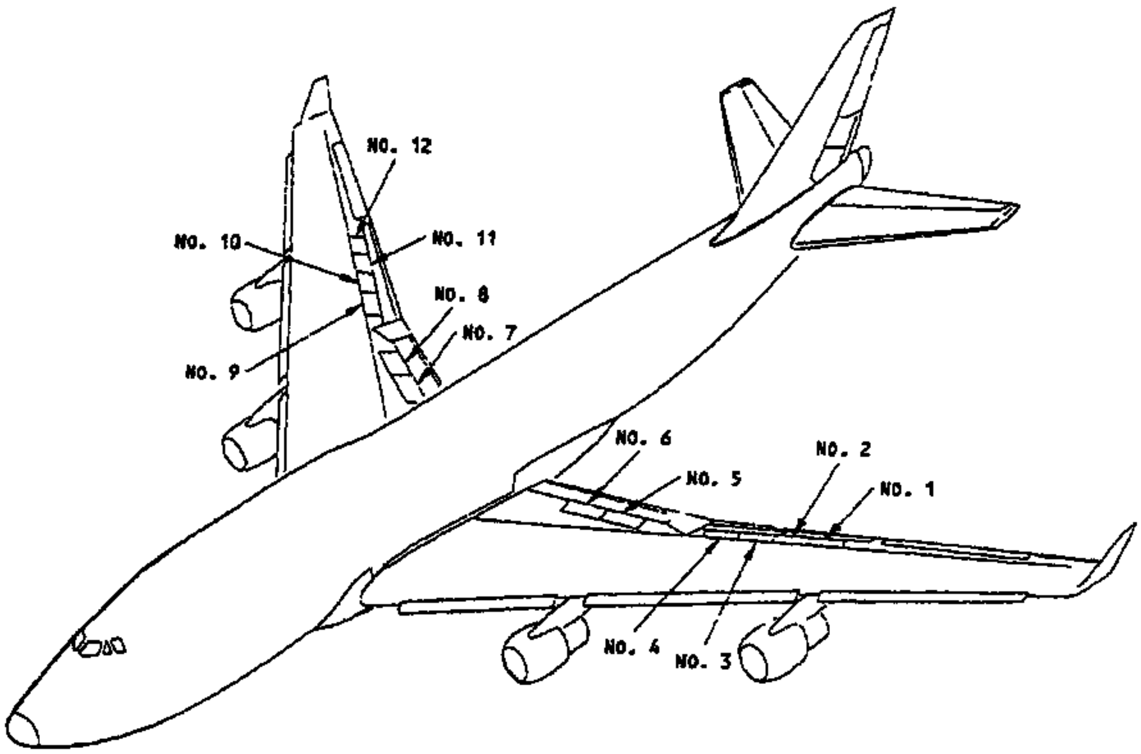


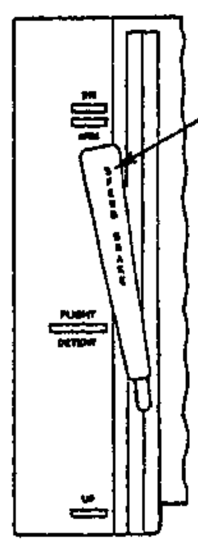
PRIMARY EICAS DISPLAY



SECONDARY EICAS DISPLAY

SPEEDBRAKE SYSTEM & SPEEDBRAKE LEVER POSITION




CONTROL STAND

SPEEDBRAKE LEVER

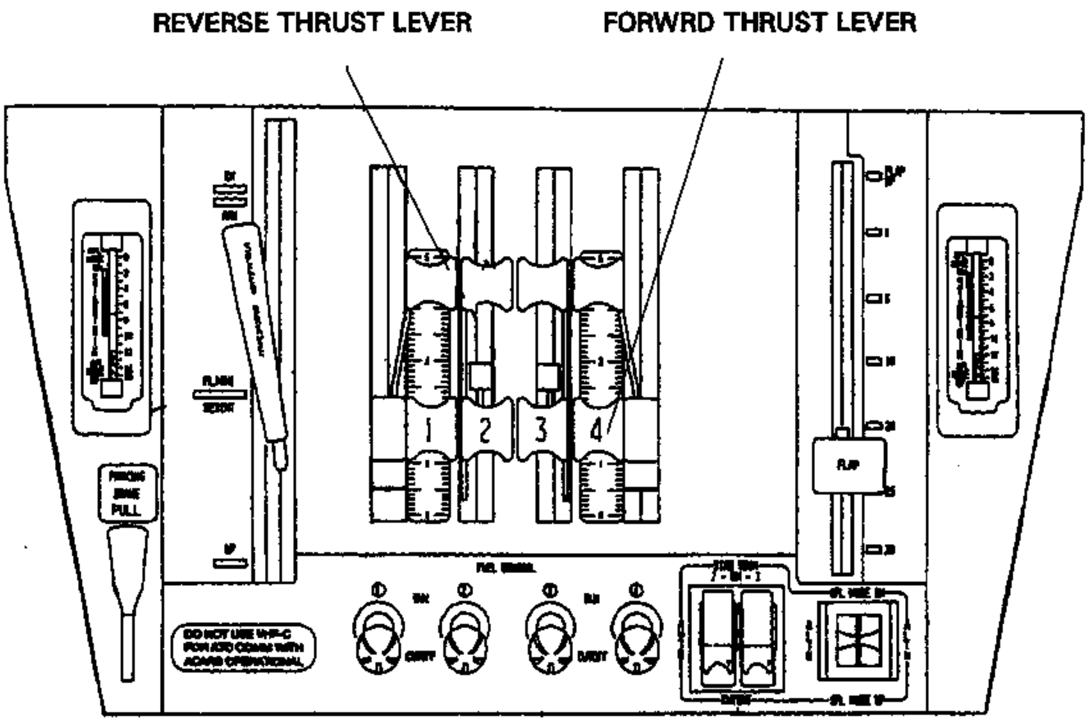
DN (detent)
- All spoiler panels retracted
- On the ground, speedbrake lever moves to UP and all spoiler panels extend when either engine 2 or engine 4 reverse thrust lever is raised to the idle detent with engine 1 and engine 3 thrust levers retarded

[ARM
- Auto ground spoiler system armed
- After landing, speedbrake lever moves to UP and spoiler panels extend if engine 1 and engine 3 thrust levers are retarded]

[FLIGHT DETENT
- Flight spoiler panels raise to their maximum in-flight positions
- Movement of lever for in-flight use is limited by a solenoid actuated stop at the Flight Detent]

UP
- All spoiler panels fully extend
- On the ground, speedbrake lever moves to DN and spoiler panels retract if engine 1 or engine 3 thrust lever is advanced

THRUST LEVER ASSEMBLY



CONTROL STAND

OBSERVATION REPORTS ISSUED BY THE AMO FROM 040000 TO 040400 HR

SUMMARY OF METEOROLOGICAL WEATHER OBSERVATIONS FOR HONG KONG INTERNATIONAL AIRPORT

Observation time (Hr UTC)	Mean wind velocity (deg/kt)	Max wind speed (kt)	Variations in wind direction (degrees)	Visibility in metres	Weather	Cloud bases (feet)	Temp (deg C) QNH (hPa)	Temporary reductions in visibility	Temporary weather	Temporary reduction in cloud bases (feet)	Warnings
04 0000	070°/17	36	020°-130°	5000	Moderate continuous rain	SCT 1400 SCT 2000 BKN 8000	24 1012	-	-	-	SIG WIND SHEAR AND MOD TURB IN APCH
04 0030	070°/20	36	360°-130°	3800	Moderate rain showers	SCT 1400 SCT 2000 BKN 4000	23 1012	3000	Moderate rain showers	SCT 1000 SCT 1500 BKN 4000	-
04 0130	06°/21	43	310°-120°	4800	Light rain showers	SCT 1200 SCT 1800 BKN 8000	23 1012	3000	Moderate rain showers	SCT 1000 SCT 1500 BKN 4000	-
04 0200	070°/22	43	340°-120°	6000	Light rain showers	SCT 2000 BKN 8000	24 1013	3000	Moderate rain showers	SCT 1000 SCT 1500 BKN 4000	-
04 0230	070°/21	45	300°-130°	6000	Light intermittent rain	SCT01400 SCT 2000 BKN 8000	24 1013	3000	Moderate rain showers	SCT 1000 SCT 1500 BKN 4000	-
04 0300	070°/21	34	010°-140°	6000	Light continuous rain	SCT 1400 SCT 2000 BKN 8000	24 1012	3000	Moderate rain showers	SCT 1000 SCT 1500 BKN 4000	WS LDG RWY 13/31
04 0330	070°/22	41	Not reported	6000	Feeble rain	SCT 1400 SCT 2000 BKN 8000	24 1012	3000	Moderate rain showers	SCT 1000 SCT 1500 BKN 4000	SIG WIND SHEAR AND MOD TURB IN APPCH
04 0343	070°/21	39	Not reported	6000	Feeble rain	SCT 1400 SCT 2000 BKN 8000	24 1012	3000	Moderate rain showers	SCT 1000 SCT 1500 BKN 4000	SIG WIND SHEAR AND MOD TURB IN APPCH
04 0400	070°/21	40	300°-110°	7000	Light continuous rain	SCT 1400 SCT 2000 BKN 8000	24 1012	3000	Moderate rain showers	SCT 1000 SCT 1500 BKN 4000	WS LDG RWY 13/31

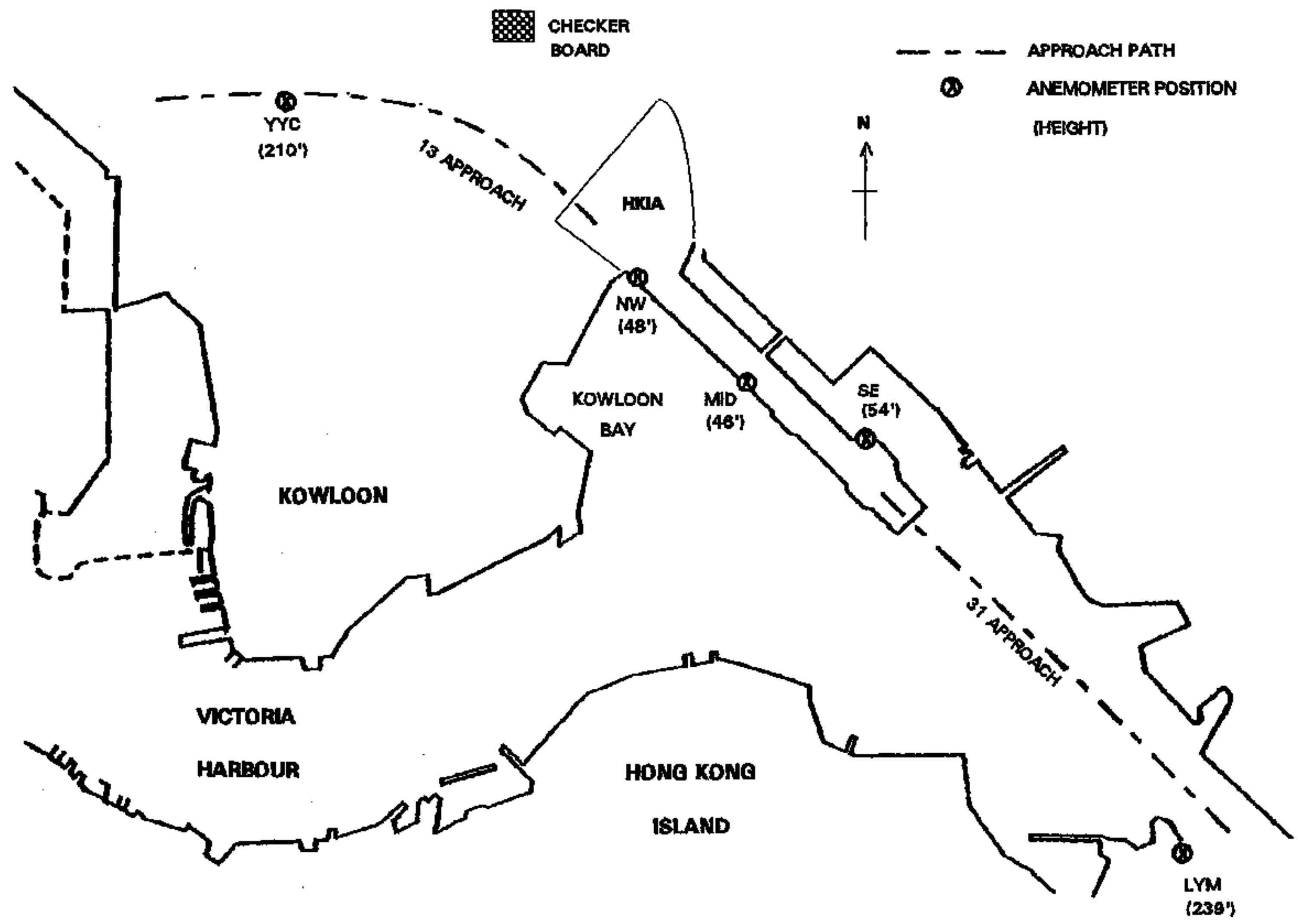
Notes:

1. The 0330 observation was disseminated to ATC by the TV display system and a record of the display was automatically recorded at 0331 hours. The 0343 hours observation was a post-accident special observation timed 7 minutes after the aircraft over-ran the runway.

POSITIONS OF ANEMOMETERS

HONG KONG LOW LEVEL WIND SHEAR DETECTION SYSTEM

POSITIONS OF ANEMOMETERS



WIND DATA FROM THE WSWS BETWEEN 03:30:00 TO 03:40:00 HR

EXPLANATION NOTES ON HARD COPY PRINTOUT OF WIND ANALYSING SYSTEM

A TYPICAL RECORD OF THE REAL-TIME HARD COPY PRINTOUT

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04-NOV-1993 THURSDAY 03:38:00
SE  A070/33 B060/23 C070/23 D330-110 E 04-  39 FR 38 L 38 GT 22 H 22    LYM A070/37 B050/34 C060/31
NW  A050/12 B060/17 C060/19 D010-110 E 09-  44 FR 41 L 41 GH 21 T 21    YYC A050/24 B060/25 C050/24
MID A060/24 B060/25 C050/22    SHEAR 31A/13D SINKING    13A/31D SIG SINKING -12  QNH XXXX
```

EXPLANATION

DD-MM-YY DAY OF WEEK HH:MM:SS UTC (HOUR:MINUTE:SECOND)

SE = SOUTHEAST; NW = NORTHWEST; MID = MID-RUNWAY; LYM = LEI YUE MUN; YYC = YAU YAT CHUEN

(A) = PRESENT WIND:
(i) MAXIMUM 1-SEC WIND SPEED & ASSOCIATED DIRECTION IN 5-SEC PERIOD.

(B) = 2-MINUTE MEAN WIND & DIRECTION:
(i) SPEED: ARITHMETIC MEAN OF 1-SEC WIND SPEEDS IN PRECEDING 2 MINUTES
(ii) DIRECTION: ARITHMETIC MEAN OF 1-SEC WIND DIRECTIONS IN PRECEDING 2 MINUTES USING ALGORITHM IN ATTACHMENT II

(C) = 10-MINUTE MEAN WIND & DIRECTION:
(i) SPEED: ARITHMETIC MEAN OF 1-SEC WIND SPEEDS IN PRECEDING 10 MINUTES
(ii) DIRECTION: ARITHMETIC MEAN OF 1-SEC WIND DIRECTIONS IN PRECEDING 10 MINUTES USING ALGORITHM IN ATTACHMENT II

(D) = SIGNIFICANT DEVIATION (DIRECTION):
(i) TWO EXTREME 1-SEC WIND DIRECTIONS RECORDED DURING THE PRECEDING 10 MINUTES
(ii) A DEVIATION >= 60 DEGREES IS TAKEN AS SIGNIFICANT, DISPLAYED IN CLOCKWISE SENCE

(E) = SIGNIFICANT DEVIATION (SPEED):
(i) MAX AND MIN 1-SEC WIND SPEEDS DURING PRECEDING 10 MINUTES
(ii) A DEVIATION >= 10 KNOTS FROM THE 10-MINUTE MEAN IS TAKEN AS SIGNIFICANT

(F) = MAXIMUM CROSS WIND COMPONENT:
(i) MAX 1-SEC CROSS-WIND COMPONENT DURING PRECEDING 10 MINUTES
(ii) LEFT COLUMN: CROSS WIND FOR RUNWAY 31
(iii) RIGHT COLUMN: CROSS WIND FOR RUNWAY 13
(iv) 'R/L' = WIND FROM RIGHT / LEFT OF PATH

(G) = MAXIMUM TRACKWIND COMPONENT:
(i) MAX 1-SEC TRACK-WIND COMPONENT DURING PRECEDING 10 MINUTES
(ii) LEFT COLUMN: TRACK WIND FOR RUNWAY 31
(iii) RIGHT COLUMN: TRACK WIND FOR RUNWAY 13
(iv) 'T/H' = TAILWIND / HEADWIND

"SHEAR 31A/13D SINKING":
(i) SINKING SHEAR < 8 KNOTS PER 100 FT, VALUE NOT SHOWN ON DISPLAY
(ii) CALCULATED FROM 30-SECOND MEAN WINDS BETWEEN LYM AND SE

"13A/31D SIG SINKING -12":
(i) SIGNIFICANT SINKING SHEAR OF 12 KNOTS/100 FT
(ii) CALCULATED FROM 30-SECOND MEAN WINDS BETWEEN YYC AND NW

FURTHER NOTES ON PRINTOUT

(1) OCCURRENCE OF SIGNIFICANT WIND SHEAR WILL ACTIVATE THE PRINTER TO PROVIDE HARD COPY PRINTOUT AT 30-SECONDS INTERVALS.
(2) IF NO SIGNIFICANT WIND SHEAR IS OBSERVED, PRINTOUT WILL BE UPDATED EVERY 10 MINUTES.
(3) SIGNIFICANT WIND SHEAR DENOTES EITHER LIFTING OR SINKING SHEAR >= 8 KT PER 100 FT (ICAO RECOMMENDATION)
(4) SIGNIFICANT WIND VARIATIONS, MAXIMUM CROSS AND TRACK WIND COMPONENTS ARE NOT COMPUTED FOR STATIONS AT MID (MID-RUNWAY), LYM (LEI YUE MUN) AND YYC (YAU YAT CHUEN).

```
04-NOV-1993  THURSDAY  03:30:00
SE  A080/ 20 B080/ 22 C070/ 22 D030-130 E 12- 38 FR 38 L 38 GT 28 H 28   LYM  A070/ 34 B060/ 31 C050/ 33
NW  A060/ 20 B060/ 17 C060/ 17 D030-110 E 09- 33 FR 33 L 33 GT 19 H 19   YYC  A050/ 30 B050/ 24 C040/ 23
MID A100/ 22 B040/ 21 C040/ 23        SHEAR    31A/13D SINKING         13A/31D SINKING           QNH XXXX

04-NOV-1993  THURSDAY  03:31:00
SE  A090/ 20 B080/ 22 C070/ 22 D030-130 E 12- 38 FR 38 L 38 GT 28 H 28   LYM  A050/ 40 B060/ 32 C050/ 33
NW  A050/ 21 B060/ 18 C060/ 17 D030-110 E 09- 33 FR 33 L 33 GT 19 H 19   YYC  A040/ 23 B040/ 24 C040/ 23
MID A050/ 27 B040/ 22 C040/ 23        SHEAR    31A/13D SINKING         13A/31D SIG SINKING -09   QNH XXXX

04-NOV-1993 THURSDAY   03:31:30
SE  A070/ 23 B080/ 22 C070/ 22 D030-130 E 12- 38 FR 38 L 38 GT 28 H 28   LYM  A060/ 35 B060/ 32 C050/ 33
NW  A050/ 20 B060/ 19 C060/ 17 D030-110 E 09- 33 FR 33 L 33 GT 19 H 19   YYC  A040/ 21 B040/ 24 C040/ 23
MID A050/ 22 B040/ 22 C040/ 23        SHEAR    31A/13D SINKING         13A/31D SIG SINKING -11   QNH XXXX

04-NOV-1993 THURSDAY   03:32:00
SE  A090/ 30 B080/ 23 C070/ 23 D030-130 E 12- 38 FR 38 L 38 GT 28 H 28   LYM  A060/ 30 B060/ 32 C050/ 32
NW  A030/ 25 B050/ 20 C060/ 18 D010-110 E 09- 37 FR 33 L 33 GH 21 T 21   YYC  A040/ 38 B040/ 24 C050/ 23
MID A030/ 22 B040/ 21 C040/ 22        SHEAR    31A/13D SINKING         13A/31D SIG SINKING -10   QNH XXXX

04-NOV-1993 THURSDAY   03:32:30
SE  A080/ 28 B080/ 25 C070/ 23 D030-130 E 12- 38 FR 38 L 38 GT 28 H 28   LYM  A060/ 31 B060/ 31 C050/ 32
NW  A060/ 19 B050/ 19 C060/ 18 D010-110 E 09- 37 FR 33 L 33 GH 21 T 21   YYC  A030/ 30 B040/ 24 C050/ 23
MID A040/ 26 B040/ 21 C040/ 22        SHEAR    31A/13D SINKING         13A/31D SIG SINKING  09   QNH XXXX

04-NOV-1993 THURSDAY   03:33:00
SE  A060/ 29 B070/ 25 C070/ 23 D030-130 E 12- 38 FR 38 L 38 GT 28 H 28   LYM  A060/ 29 B060/ 30 C050/ 32
NW  A070/ 22 B050/ 20 C060/ 18 D010-110 E 09- 37 FR 33 L 33 GH 21 T 21   YYC  A040/ 16 B040/ 23 C050/ 23
MID A050/ 28 B040/ 22 C040/ 22        SHEAR    31A/13D SINKING         13A/31D SIG SINKING -08   QNH XXXX

04-NOV-1993 THURSDAY   03:34:00
SE  A050/ 36 B070/ 25 C070/ 23 D030-110 E 12- 39 FR 38 L 38 GT 28 H 28   LYM  A060/ 28 B060/ 28 C060/ 31
NW  A070/ 27 B060/ 21 C060/ 19 D010-110 E 09- 37 FR 35 L 35 GH 21 T 21   YYC  A060/ 35 B040/ 24 C050/ 23
MID A050/ 29 B050/ 25 C050/ 22        SHEAR    31A/13D NO SHEAR        13A/31D SIG SINKING -09   QNH XXXX

04-NOV-1993 THURSDAY   03:34:30
SE  A050/ 30 B060/ 24 C070/ 23 D030-110 E 12- 39 FR 38 L 38 GT 28 H 28   LYM  A060/ 31 B060/ 29 C060/ 31
NW  A050/ 28 B060/ 22 C060/ 19 D010-110 E 09- 37 FR 35 L 35 GH 21 T 21   YYC  A110/ 23 B060/ 24 C050/ 23
MID A050/ 23 B050/ 25 C050/ 22        SHEAR    31A/13D NO SHEAR        13A/31D SIG SINKING -12   QNH XXXX

04-NOV-1993 THURSDAY   03:35:00
SE  A070/ 23 B060/ 23 C070/ 23 D030-110 E 12- 39 FR 38 L 38 GT 28 H 28   LYM  A050/ 34 B060/ 30 C060/ 31
NW  A060/ 21 B070/ 22 C060/ 19 D010-110 E 09- 37 FR 35 L 35 GH 21 T 21   YYC  A050/ 29 B060/ 24 C050/ 23
MID A070/ 24 B060/ 24 C050/ 22        SHEAR    31A/13D NO SHEAR        13A/31D SIG SINKING -08   QNH XXXX

04-NOV-1993 THURSDAY   03:35:30
SE  A070/ 21 B070/ 23 C070/ 23 D030-110 E 12- 39 FR 38 L 38 GT 28 H 28   LYM  A360/ 32 B060/ 31 C060/ 31
NW  A060/ 37 B060/ 23 C060/ 19 D010-110 E 09- 37 FR 35 L 35 GH 21 T 21   YYC  A060/ 33 B060/ 25 C050/ 23
MID A040/ 19 B060/ 23 C050/ 22        SHEAR    31A/13D SINKING         13A/31D SIG SINKING -08   QNH XXXX

04-NOV-1993 THURSDAY   03:37:30
SE  A060/ 28 B060/ 20 C070/ 23 D330-110 E 07- 39 FR 38 L 38 GT 22 H 22   LYM  A020/ 39 B050/ 33 C060/ 31
NW  A070/ 21 B070/ 18 C060/ 19 D010-110 E 09- 44 FR 41 L 41 GH 21 T 21   YYC  A060/ 20 B050/ 24 C050/ 24
MID A060/ 25 B050/ 24 C050/ 22        SHEAR    31A/13D SINKING         13A/31D SIG SINKING -11   QNH XXXX

04-NOV-1993 THURSDAY   03:38:00
SE  A070/ 33 B060/ 23 C070/ 23 D330-110 E 04- 39 FR 38 L 38 GT 22 H 22   LYM  A070/ 37 B050/ 34 C060/ 31
NW  A050/ 12 B060/ 17 C060/ 17 D010-110 E 09- 44 FR 41 L 41 GH 21 T 21   YYC  A050/ 24 B060/ 25 C050/ 24
MID A060/ 24 B060/ 25 C050/ 22        SHEAR    31A/13D SINKING         13A/31D SIG SINKING -12   QNH XXXX
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04-NOV-1993 THURSDAY   03:38:30
SE  A040/ 23 B070/ 25 C070/ 23 D330-110 E 04- 39 FR 38 L 38 GT 22 H 22   LYM  A060/ 35 B050/ 35 C060/ 31
NW  A060/ 13 B060/ 15 C060/ 19 D010-110 E 09- 44 FR 41 L 41 GH 21 T 21   YYC  A050/ 37 B050/ 25 C050/ 24
MID A040/ 18 B060/ 23 C050/ 22        SHEAR    31A/13D LIFTING        13A/31D SIG SINKING -09   QNH XXXX

04-NOV-1993 THURSDAY   03:39:00
SE  A060/ 33 B060/ 27 C070/ 23 D330-110 E 04- 39 FR 38 L 38 GT 22 H 22   LYM  A060/ 33 B050/ 35 C060/ 31
NW  A030/ 11 B060/ 14 C060/ 19 D010-110 E 09- 44 FR 41 L 41 GH 21 T 21   YYC  A040/ 29 B060/ 25 C050/ 24
MID A060/ 27 B050/ 23 C050/23         SHEAR    31A/13D SINKING        13A/31D SIG SINKING -10   QNH XXXX

04-NOV-1993 THURSDAY   03:40:00
SE  A060/ 22 B060/ 25 C070/ 24 D330-110 E 04- 39 FR 38 L 38 GT 22 H 22   LYM  A040/ 38 B050/ 33 C060/ 32
NW  A040/ 17 B060/ 12 C060/ 16 D010-110 E 08- 44 FR 41 L 41 GH 21 T 21   YYC  A050/ 30 B050/ 25 C050/ 24
MID A040/ 28 B050/ 22 C050/ 23        SHEAR    31A/13D SINKING        13A/31D SIG SINKING -12   QNH XXXX
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RADIOTELEPHONY CONVERSATION BETWEEN THE CREW AND THE AIR MOVEMENTS CONTROLLER ON 118.7 MHz

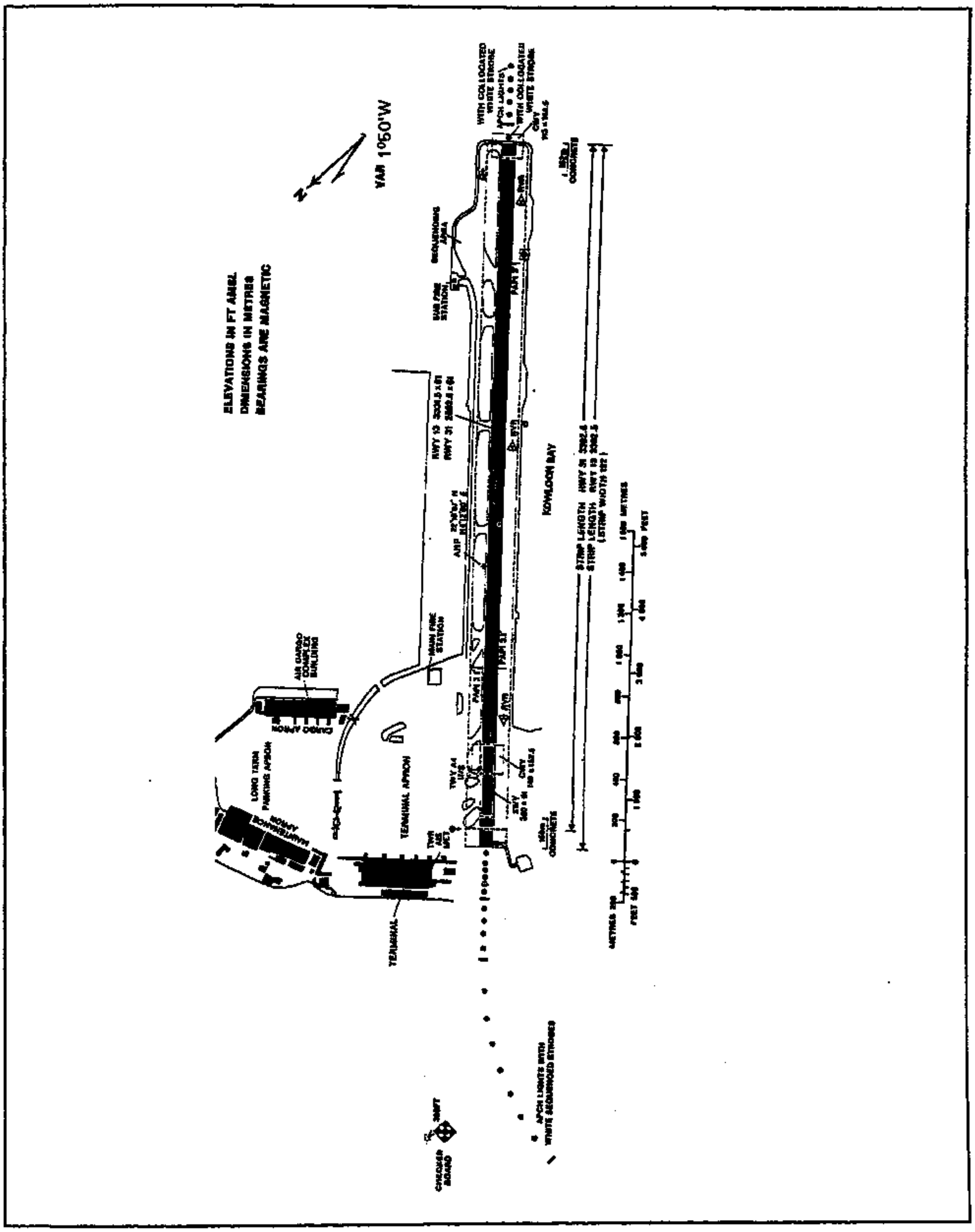
The following transcription covers the time period from 0328 to 0336 UTC on 4 November 1993. It is a true transcription of the recorded conversation on the Air Movements Control (AMC) Frequency 118.7 MHz pertaining to the subject accident.

Time (UTC) (hr:min:sec)	From	To	Communication
03:28:56	CAL 605	TWR	Hong Kong Tower good morning. Dynasty Six Zero Five. IGS.
03:29:00	TWR	CAL 605	Dynasty Six Zero Five good morning. Report passing the Outer Marker. Wind zero six zero degrees two two knots. Visibility reduced to five thousand metres in rain.
03:29:09	CAL 605	TWR	Dynasty Six Zero Five. Report Outer Er Outer Marker.
03:30:12	CPA 450	TWR	Cathay Four Five Zero is Holding Point One Three. Will be ready in two minutes.
03:30:16	TWR	CPA 450	Cathay Four Five Zero Roger. Hold at the Holding Point. Report when ready.
30:30:20	CPA 450	TWR	Four Five Zero.
03:31:52	CPA 450	TWR	Cathay Four Five Zero ready for departure.
03:31:55	TWR	CPA 450	Cathay Four Five Zero. Roger. Line Up.
03:31:58	CPA 450	TWR	Line up One Three. Cathay Four Five Zero.
03:32:02	TWR	CES 5011	China Eastern Five Zero One One take taxiway left Bravo One. Contact Ground one two one six.
03:32:05	CES 5011	TWR	One Two One Six Good day.

Time (UTC) (hr:min:sec)	From	To	Communication
03:32:29	TWR	CPA 450	Cathay Four Five Zero. Wind zero six zero degrees two eight knots. Cleared for take-off.
03:32:36	CPA 450	TWR	Cleared for take-off One Three. Cathay Four Five Zero.
03:32:40	KAL 617	TWR	Hong Kong Tower. Korean Six One Seven approaching Outer Marker.
03:32:44	TWR	KAL 617	Korean Six One Seven. Tower. Report passing the Outer Marker. Wind zero six zero degrees two five knots.
03:32:51	KAL 617	TWR	Er Korean Six One Seven. Report Outer Marker. Say again wind condition.
03:32:57	TWR	KAL 617	Korean Six One Seven. Touchdown wind zero six zero degrees two five knots.
03:33:03	KAL 617	TWR	Six One Seven. Thank you.
03:33:13	CAL 605	TWR	Tower. Dynasty Six Zero Five. Outer Marker.
03:33:16	TWR	CAL 605	Dynasty Six Zero Five continue approach.
03:33:18	CAL 605	TWR	Six Zero Five.
03:33:21	CPA 450	TWR	Cathay Four Five Zero is rolling.
03:33:22	TWR	CPA 450	Roger.
03:33:58	TWR	CAL 605	Dynasty Six Zero Five touchdown wind zero seven zero degrees two five knots. Expect sinking windshear turning short final. Cleared to land.
03:34:07	CAL 605	TWR	Cleared to land and copied. Thank you.

Time (UTC) (hr:min:sec)	From	To	Communication
03:34:33	TWR	CPA 450	Cathay Four Five Zero contact Approach one one nine one.
03:34:36	CPA450	TWR	Good day.
03:34:42	TWR	CPA 450	Cathay Four Five Zero contact Approach one one nine one.
03:34:48	THA 605	TWR	Hong Kong Tower. Thai Inter Six Zero Five. Approaching Holding Point One Three.
03:34:54	TWR	THA 605	Thai Inter Six Zero Five hold at the Holding Point. Report ready.
03:34:58	THA 605	TWR	Thai Inter Six Zero Five.
03:35:02	SIA 1	TWR	Tower. Singapore One holding abeam Bay 2.
03:35:06	TWR	SIA 1	Singapore One. Number Two for departure.
03:35:09	SIA 1	TWR	Singapore One.
03:35:37	THA 605	TWR	Thai Inter Six Zero Five is ready.
03:35:40	TWR	THA 605	Thai Inter Six Zero Five line up and wait.
03:35:44	THA 605	TWR	Line up and wait. Thai Inter Six Zero Five.
03:36:07	SIA 1	TWR	Singapore One. May we taxi forward to Holding Point?
03:36:12	TWR	SIA 1	Affirm. Taxi Forward to hold at Holding Point.
03:36:14	SIA 1	TWR	Singapore One.
03:36:55	TWR	THA 605	Thai Inter Six Zero Five the preceding landing has crashed. Hold position on the runway.

PLAN DIAGRAM OF HONG KONG INTERNATIONAL AIRPORT



CVR TRANSCRIPT DURING FINAL APPROACH AND LANDING PHASES

Time to End	RTF COMMUNICATION			FLIGHT DECK COMMUNICATION		REMARKS
	FROM	TO		ORIGIN		
3:30	CAL 605	TWR	TOWER DYNASTY SIX ZERO FIVE OUTER MARKER			
	TWR	CAL 605	DYNASTY SIX ZERO FIVE CONTINUE APPROACH			
3:25	CAL 605	TWR	SIX ZERO FIVE			
	CPA 450	TWR	CATHAY FOUR FIVE ZERO IS ROLLING			
	TWR	CPA 450	ROGER			CHIMES
				P1	OK FLAPS THIRTY	(CABIN CREW
				P2	FLAPS THIRTY	CALL?)
				P1	THIRTY....(UNINTELLIGIBLE)	CHIMES
				P2	LANDING CHECK	
3:04				P2	AUTOBRAKE SET TWO	CHIME
				P2	SPEEDBRAKES	
				P1	ARMED	CHIME
2:58				P2	LANDING GEARS DOWN	
					FLAPS(?) THIRTY (UNINTELLIGIBLE)	
				P1	GOT THE CHECKERBOARD GOT THE CHECKERBOARD ROGER 跟我講一下 OK [IF YOU CAN SEE THE CHECKBOARD TELL ME]	

[ ] ENGLISH TRANSLATION

Time to End	RTF COMMUNICATION			FLIGHT DECK COMMUNICATION		REMARKS
	FROM	TO		ORIGIN		
2:42	TWR	CAL 605	DYNASTY SIX ZERO FIVE TOUCHDOWN WIND ZERO SEVEN ZERO DEGREES TWO FIVE KNOTS EXPECT SINKING WINDSHEAR TURNING SHORT FINAL CLEARED TO LAND			
2:33	CAL 605	TWR	CLEARED TO LAND AND COPIED THANK YOU	P2	070025	
2:27				P2	COULDN'T HEAR WINDSHEAR... (UNINTELLIGIBLE)	WARNING TONE
				P1	未 (UNINTELLIGIBLE WORDS IN CHINESE) [NOT YET (UNINTELLIGIBLE WORDS IN CHINESE)]	
				P2	未 (UNINTELLIGIBLE WORDS IN CHINESE) YES SIR [NOT YET (UNINTELLIGIBLE WORDS IN CHINESE) YES SIR]	
						CHIME (AT DISC?) CHIME (AT DISC?)
				P1	那個 SPEED [THAT SPEED]	
2:14				P2	SPEED BUG 不(?)見了 [SPEED BUG MISSING]	
				P1	SPEED BUG ROGER	

[ ] ENGLISH TRANSLATION

Time to End	RTF COMMUNICATION			FLIGHT DECK COMMUNICATION		REMARKS
	FROM	TO		ORIGIN		
				P1	WHOP(?)...(UNINTELLIGIBLE) ALARM OK	WARNING TONE
				P2	奇怪 [STRANGE]	
				P1	153 好了 [153 OK]	
	TWR	CPA 450	CATHAY FOUR FIVE ZERO CONTACT APPROACH ONE ONE NINE ONE			
	CPA 450	TWR	GOODDAY			
				P2	(UNINTELLIGIBLE WORD IN CHINESE) 風這麼大 [(UNINTELLIGIBLE WORD IN CHINESE) WIND SO STRONG]	VOICE ALERT MINIMUMS
1:57	TWR	CPA 450	CATHAY FOUR FIVE ZERO CONTACT APPROACH ONE ONE NINE ONE			
	THA 605	TWR	HONGKONG TOWER THAI INTER SIX ZERO FIVE APPROACHING HOLDING POINT ONE THREE			
	TWR	THA 605	THAI INTER SIX ZERO FIVE HOLD AT THE HOLDING POINT REPORT READY	P2	SPEED MINUS FIVE	
	THA 605	TWR	THAI INTER SIX ZERO FIVE			
1:43				P2	PLUS TEN	

[ ] ENGLISH TRANSLATION

Time to End	RTF COMMUNICATION			FLIGHT DECK COMMUNICATION		REMARKS
	FROM	TO		ORIGIN		
				P1	WINDSHEAR AT ... (UNINTELLIGIBLE)	
					WINDSHEAR	
	SIA 1	TWR	TOWER SINGAPORE ONE HOLDING ABEAM BAY TWO			
	TWR	SIA 1	SINGAPORE ONE NUMBER TWO FOR DEPARTURE			
	SIA 1	TWR	SINGAPORE ONE			
				P2	四百七 [FOUR HUNDRED SEVEN]	
						VOICE ALERT GLIDESLOPE WINDSHEAR WINDSHEAR
1:21						WINDSHEAR GLIDESLOPE
1:14						GLIDESLOPE
				P2	SPEED MINUS FIVE	
1:09						GLIDESLOPE
1:01				P2	ONE HUNDRED	
				P1	是呀 [YES]	
0:54	THA 605	TWR	THAI INTER SIX ZERO FIVE IS READY			
	TWR	THA 605	THAI INTER SIX ZERO FIVE LINE UP AND WAIT	P2	FIFTY	

[ ] ENGLISH TRANSLATION

Time to End	RTF COMMUNICATION			FLIGHT DECK COMMUNICATION		REMARKS
	FROM	TO		ORIGIN		
	THA 605	TWR	LINE UP AND WAIT THAI INTER SIX ZERO FIVE	P2	THIRTY	
				P2	TWENTY	
				P2	TEN	
0:46				P2	FIVE-ZERO	CLICKING SOUND
				P2	是呀 [YES]	
				P2	我壓杆 [I ROLL STICK]	CLICKING SOUND
				P1	等一下....不要壓太多 不要壓太多 [WAIT A MOMENT...DON'T ROLL TOO MUCH...DON'T ROLL TOO MUCH]	
				P2	我....沒有我沒有壓 [I...HAVEN'T I HAVEN'T ROLL]	
				P1	對 [RIGHT]	
0:27	SIA 1	TWR	SINGAPORE ONE MAY WE TAXY FORWARD TO HOLDING POINT	P2	AUTOBRAKES 沒有了....啊 SIR REVERSE [AUTOBRAKES DON'T HAVE... OH SIR REVERSE]	CLICKING SOUND
				P2	糟了糟了糟了糟 [HO NO OH NO OH NO OH]	SOUND OF ENGINE INCREASES

[ ] ENGLISH TRANSLATION

Time to End	RTF COMMUNICATION			FLIGHT DECK COMMUNICATION		REMARKS
	FROM	TO		ORIGIN		
	TWR	SIA 1	AFFIRM TAXY FORWARD TO HOLD AT HOLDING POINT			SOUND OF ENGINE DECREASE
0:06	SIA 1	TWR	SINGAPORE ONE	P1	怎麼...... (CHINESE EXPLETIVE DELETED) [WHY ... (CHINESE EXPLETIVE DELETED]	CLICKING SOUND
				P2	這回我怎麼那麼 [THIS TIME I WHY THEN ...]	PANICKY TONE
						SOUND OF SPLASH
0:00					END OF RECORDING	

[ ] ENGLISH TRANSLATION

DFDR GRAPHS

PLOTTED PARAMETERS KEY

PARAMETER	GRAPH TITLE	POSITIVE SENSE
Angle of Attack	BODY AOA	a/c nose up
Barometric Altitude	ALTITUDE	
Computed Airspeed	CAS	
Control wheel roll angle	WHEEL	wheel to right
Control wheel pitch angle	COLUMN	column forward
Drift angle	DRIFT	right
FMC Wind Speed	WIND SPEED	
FMC Wind Direction	WIND DIR	
Glideslope Deviation	GLID DEV	fly down
GPWS Glideslope alert	G'SLOPE	
GPWS Windshear caution	W'SHEAR	
Heading	HEADING	
Lateral acceleration	LATERAL G	to the right
Localiser Deviation	LOC DEV	fly right
Longitudinal Acceleration	LONGITUDINAL G	forwards
Middle marker	M MARKER	
N1	N1	
Normal acceleration	NORMAL G	upwards
Pitch angle	PITCH	a/c nose up
Radio altitude	RADIO ALTITUDE	
Roll angle	ROLL	right wing down
Rudder Pedal position	RUD PEDAL	left rudder
Speedbrake lever position	SPDBRK LEVER	
Thrust reverser deployed	REVERSE DEPLOYED	
Thrust reverser in transit	REVERSE IN TRANSIT	
Vertical speed	IN VERT SP	upwards

Fig. 1 DFDR parameters against time from 1700 ft on the approach
Fig. 2 DFDR parameters against time from 1700 ft on the approach
Fig. 3 DFDR parameters synchronised with CVR information
Fig. 4 DFDR parameters synchronised with CVR information
Fig. 5 DFDR relative to runway position
Fig. 6 Engine parameters against time for the previous landing
Fig. 7 Engine parameters against time for the accident landing

FIGURE 1

SELECTED DFDR PARAMETERS FROM 1700 FT ON THE APPROACH

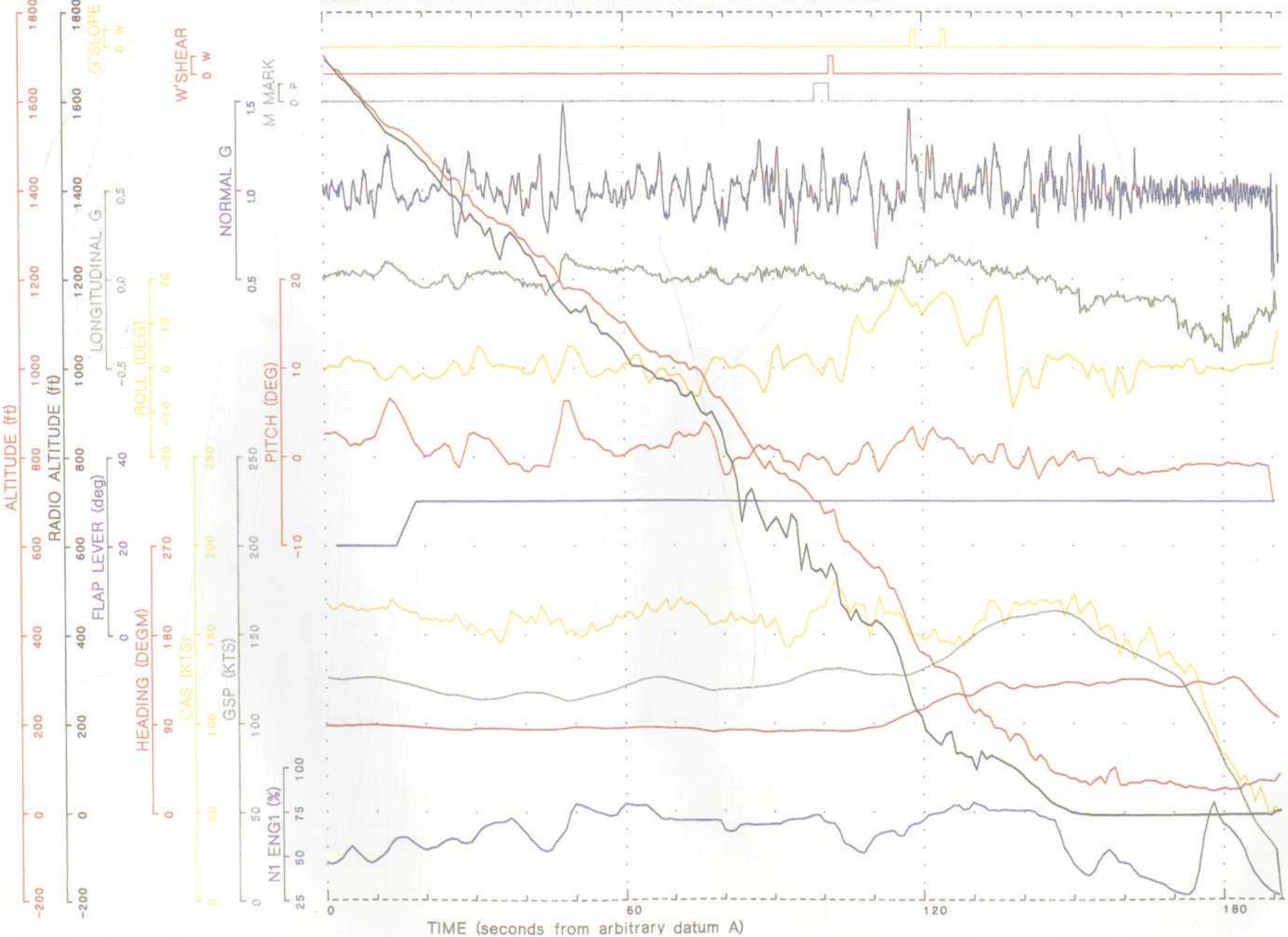
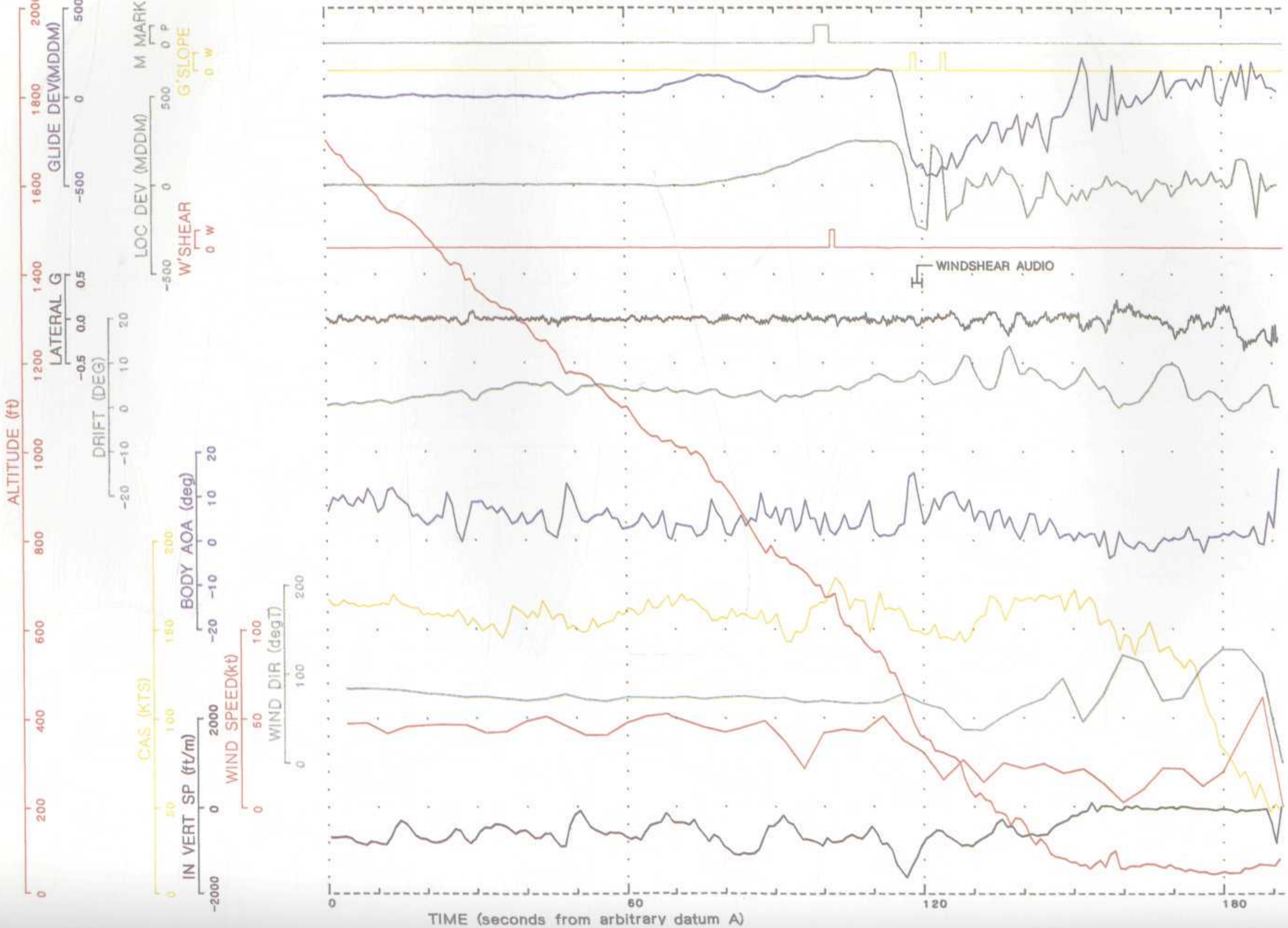


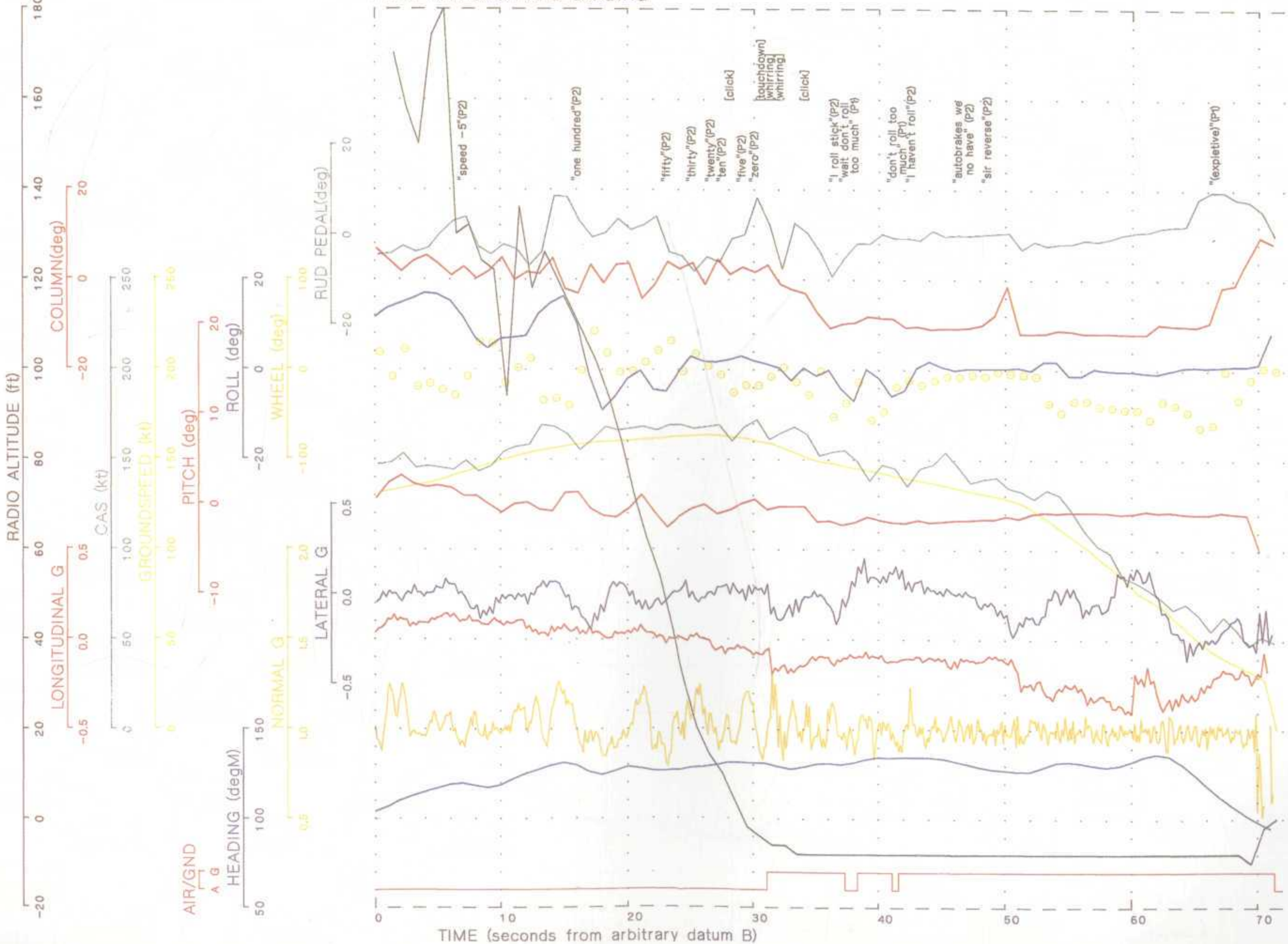
FIGURE 2

SELECTED DFDR PARAMETERS FROM 1700 FT ON THE APPROACH



SELECTED DFDR PARAMETERS SYNCHRONISED WITH CVR INFORMATION
FINAL APPROACH AND LANDING

FIGURE 3



SELECTED DFDR PARAMETERS SYNCHRONISED WITH CVR INFORMATION
FINAL APPROACH AND LANDING

FIGURE 4

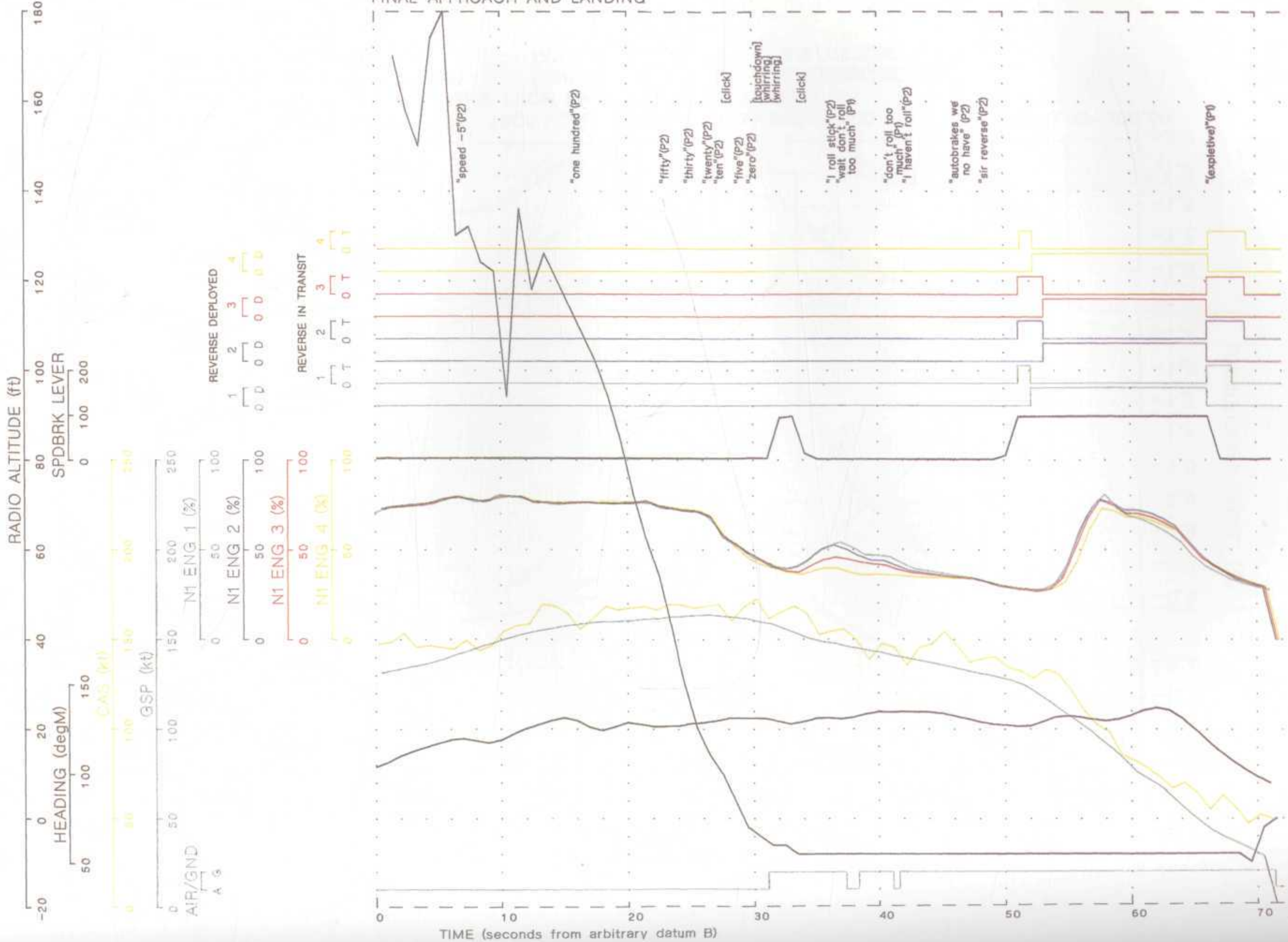


Figure 5

SELECTED DFDR PARAMETERS RELATIVE TO RUNWAY POSITION

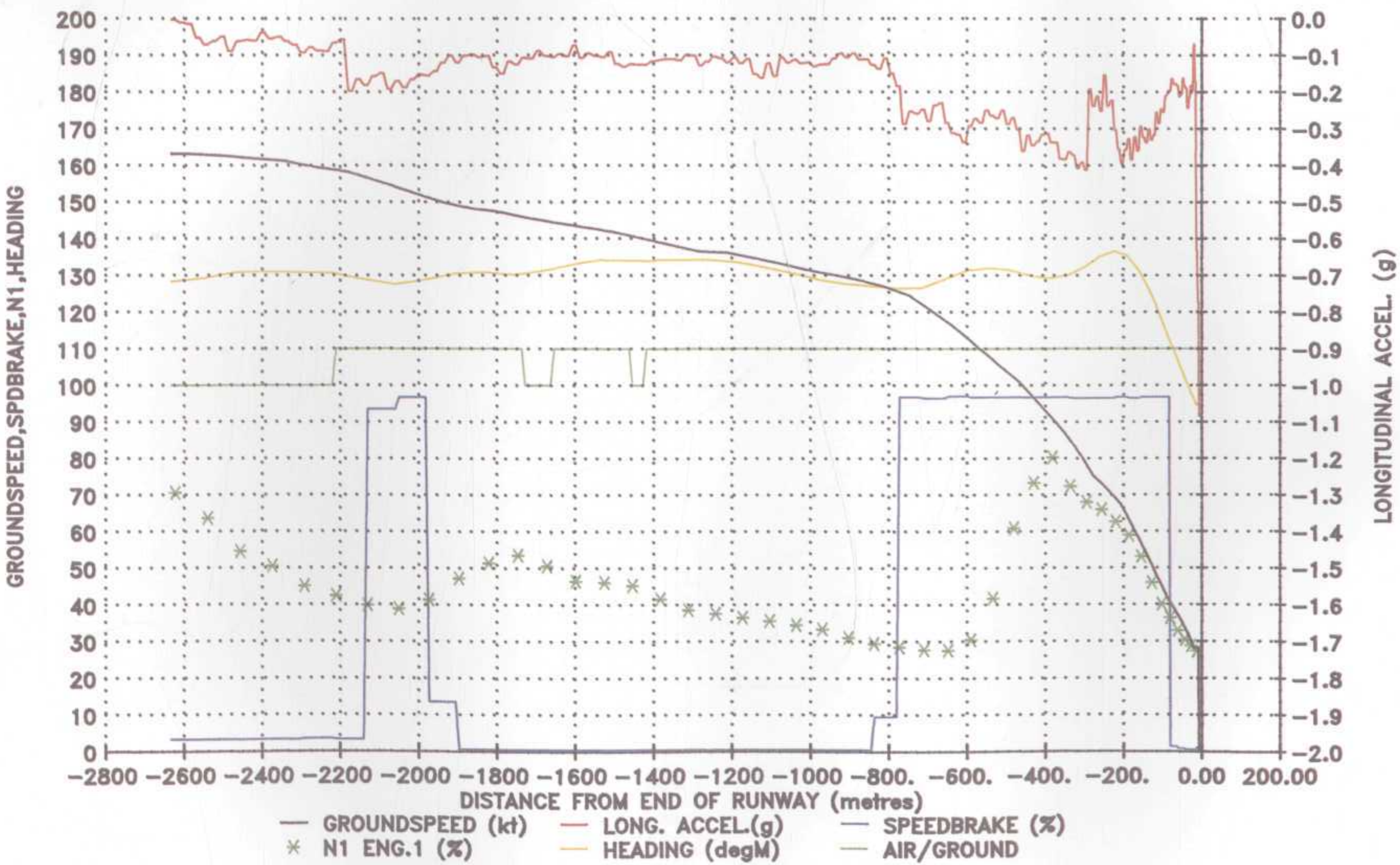
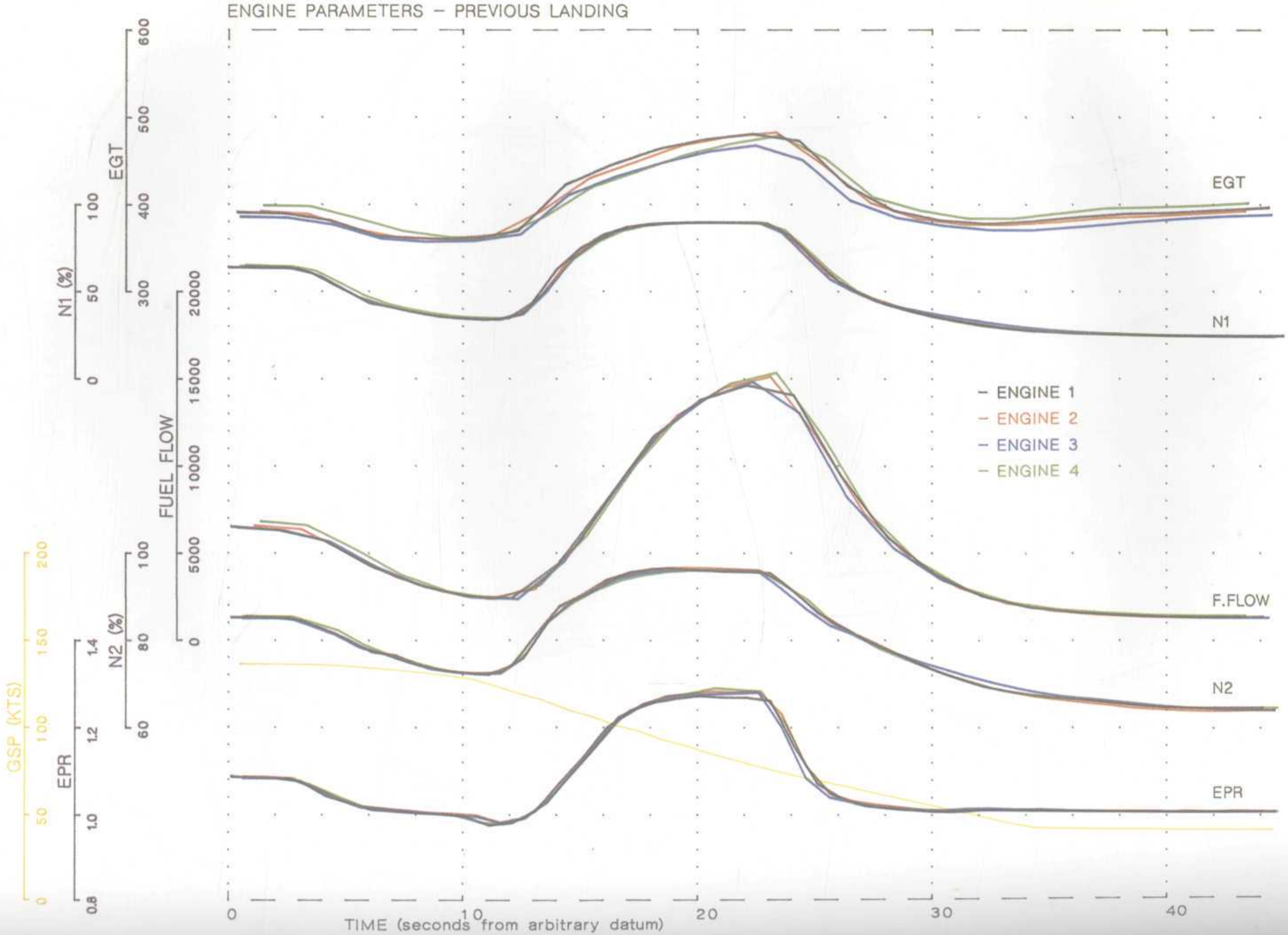
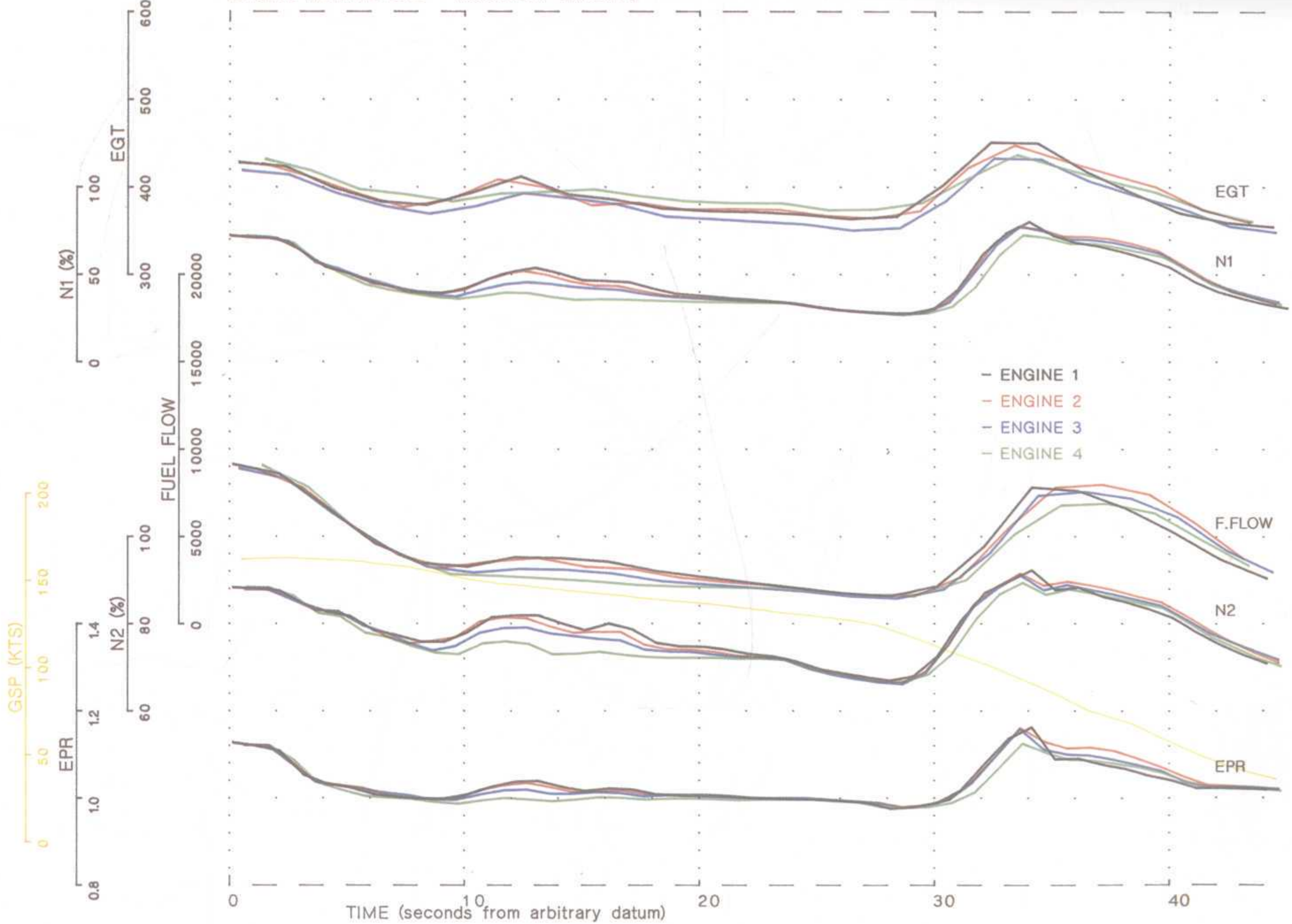


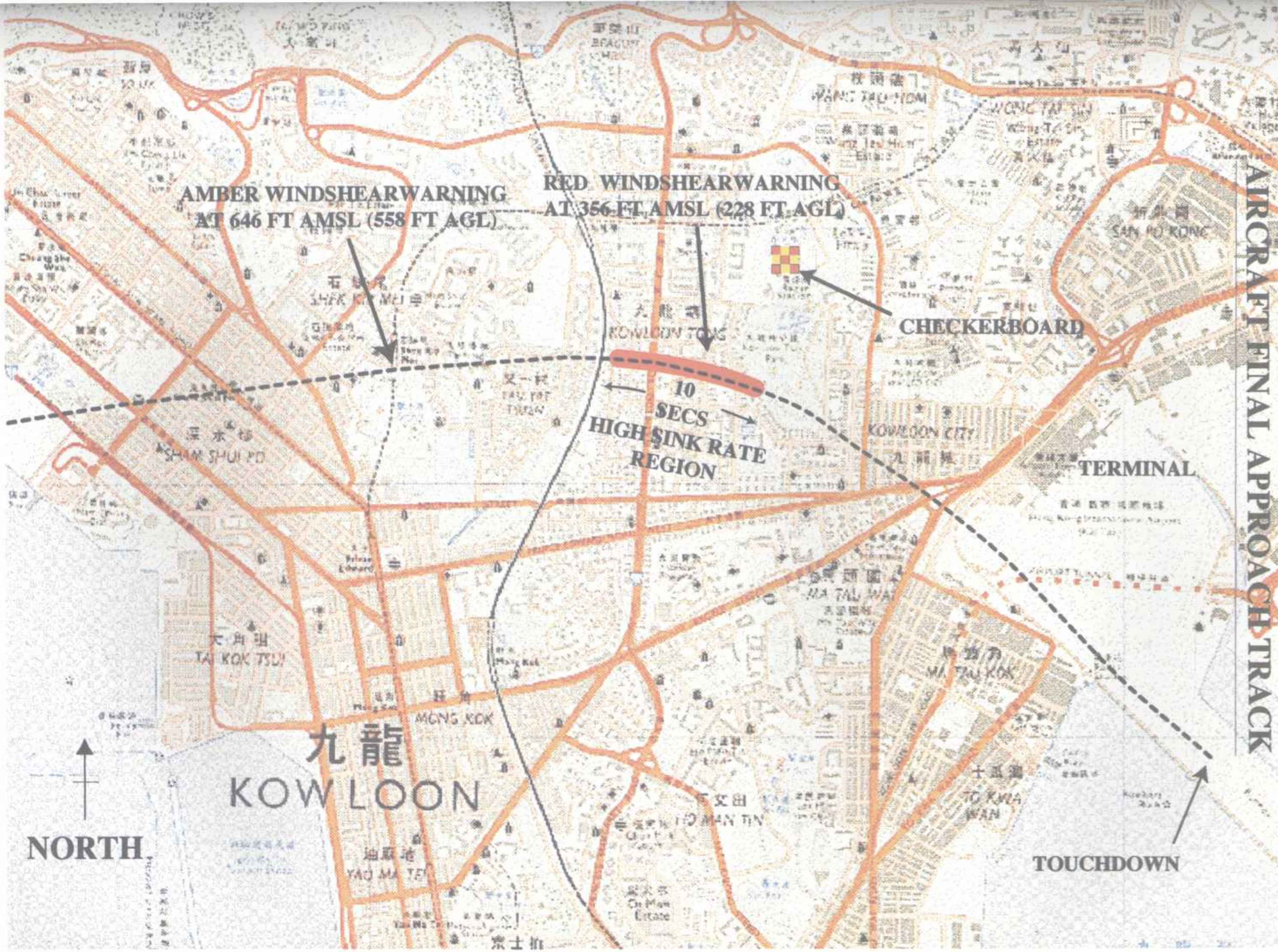
Figure 6



ENGINE PARAMETERS - PREVIOUS LANDING
EGT
N1 (%)
FUEL FLOW
N2 (%)
EPR
GSP (KTS)
EGT
N1
F.FLOW
N2
EPR
- ENGINE 1
- ENGINE 2
- ENGINE 3
- ENGINE 4
TIME (seconds from arbitrary datum)

ENGINE PARAMETERS – ACCIDENT LANDING



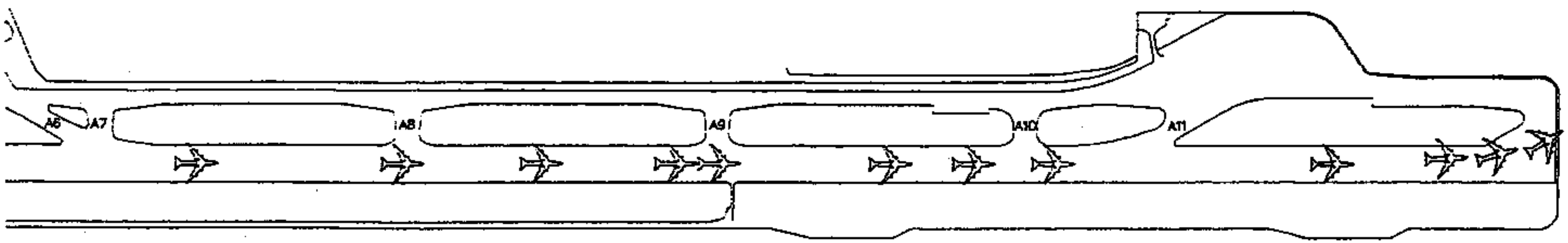


AIRCRAFT FINAL APPROACH TRACK

CAL 605 Aircraft Accident on 4 November 1993

Significant events during the landing roll

at corresponding position on the runway



Approx. elapsed time (sec) fr. T/D	0	-	-	-	-	—	-	-	+20	-	+27	-	+39
Event	Touchdown	Control Wheel handover to P2	P2 : ? roll alive	Aircraft experiences roll excursion track	Pilots take action to control a/c attitude	—	P2: No Autobrake	P2: Reverse	-	-	No.1 Engine reached peak EPR 1.162	Left rudder input, a/c starts to leave C.L.	Nose dropped, a/c Overran into sea
Distance to Seawall	2210 m	-	1800 m	-	-	—	1080 m	900 m	800 m	-	350 m	120 m	0
Ground Speed	160 kt	-	146 kt	144 kt	138 kt	—	133 kt	130 kt	127 kt	-	89 kt	-	30 kt
Spoilers	Deployed	S/B lever moving forward	Stowed	Stowed	Stowed	—	Stowed	Stowed	Deployed	-	Deployed	Deployed	Stowed
Wheel Brake	Autobrake 2	-	Disarmed	Disarmed	Disarmed	—	Manual	Manual	Manual	-	Manual	Manual	Manual
Thrust Reverser	Stowed	Stowed	Stowed	Stowed	Stowed	—	Stowed	Stowed	Selected	-	Selected	Selected	Stowed

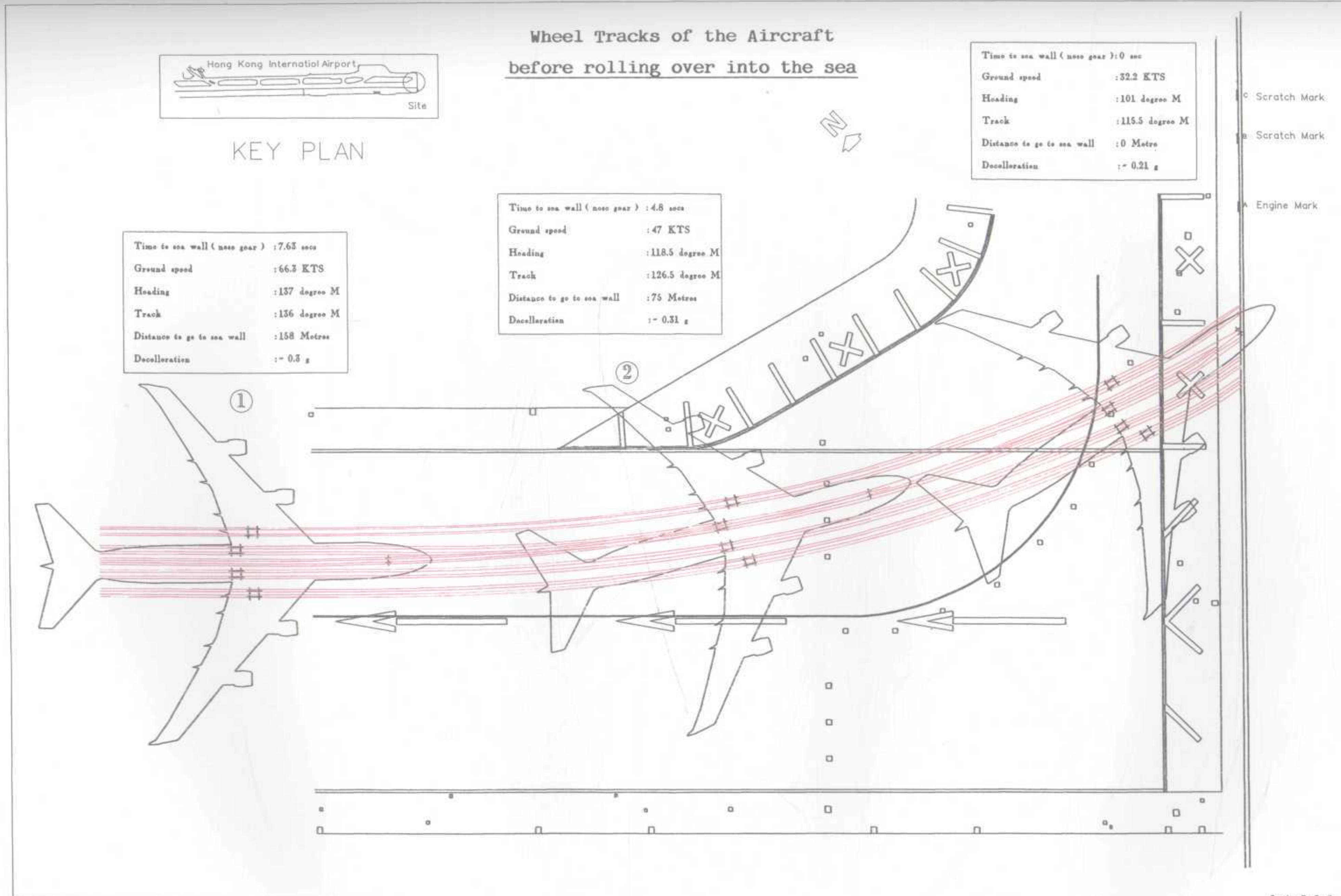


Photo Number :	72998, 72999, 73000, 73001	Surveyed :	So W. K.	Aircraft Accident at Hong Kong International Airport on 4 . 11. 93 (Boeing 747 - 400, REG B165)	Photogrammetric Unit - Lands Department - Hong Kong
Date of Photography :	5 November 1993	Processed :	So W. K.		115 - 93 A
Control Co-ordinates :	H.K. 1980 Metric Grid	Checked :	Eddy Choi		
Control Heights :	H.K. Principal Datum	Approved :	Kwok C. W.		
Folder Number :	404 Part II				

Note :
1. Position of scratch marks are measured in field by Geodetic Section of Survey and Mapping Office
2. Aircraft positions supplied by Civil Aviation Department

AIRCRAFT DAMAGE EXAMINATION REPORT

1. Airframe Damage

Damage to the aircraft's structure occurred solely as a result of its departure from the end of the runway 13 into the water and subsequently as it came to rest against the approach lighting structures close to the sea wall. As the aircraft entered the water the nose section was damaged, the right outer engine pylon failed partially releasing engine No. 4, engine No. 3 detached completely along with the inner right aft flap, and large sections of the wing/body fairing were removed. Damage was also caused by contact with the sea wall to the No. 1 engine, underside of the left outer wing, outboard section of the left flaps and rear fuselage in the region of the APU. Upward movement of the APU structure caused some crushing damage to the lower rudder. The main structural elements of the aircraft, wing box, fuselage aft of the nose gear/forward of APU, fin and horizontal stabiliser, received no significant damage as a direct result of the accident.

After drifting back towards the sea wall at the end of the runway, damage was caused to the right horizontal stabiliser, engine No. 1 and No. 2 and left outer wing leading edge, by wave induced motion against lighting structures and sub-surface obstructions. Further damage was caused during the salvage operation, including removal of the fin by explosive cutting and cutting into the floor and landing gear areas for access.

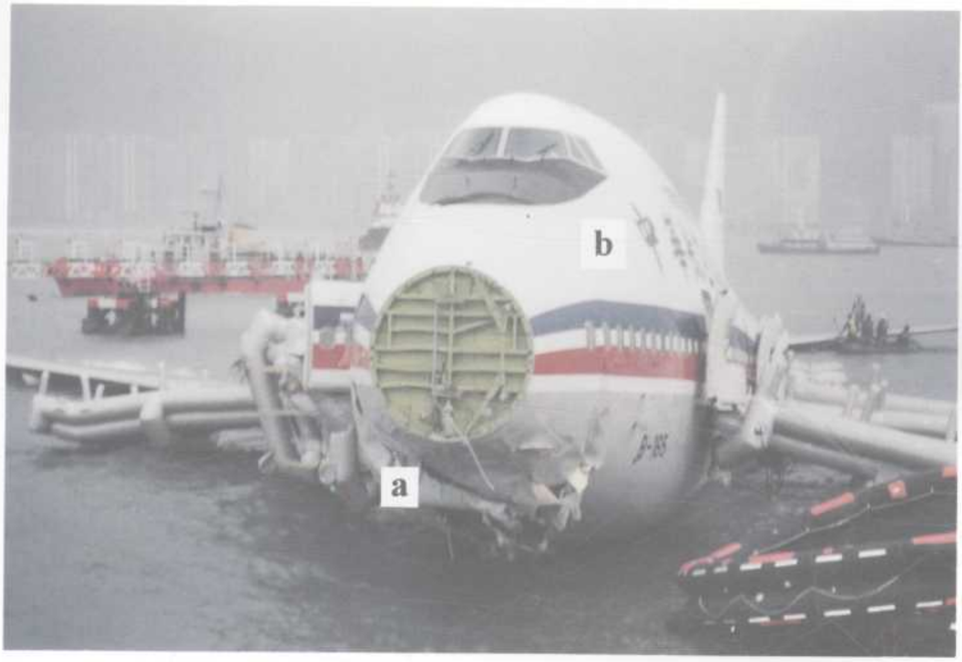
The airframe damage is shown and described in Figure A to H.

Figure A

General view of aircraft in relation to runway 13 end, sea wall, tyre tracks and approach lighting structures

Figure B

Damage occasioned to rear fuselage structure by contact with the sea wall; APU cone was pushed up into lower rudder



Damage to aircraft nose structure caused by water impact pressure centred on area 'a'. Complete section forward of station 220 moved aftwards, pivoting about area 'b' with resulting compression creasing around the fuselage circumference

Figure C

Damage to engine No 1 from sea wall strike along line 'a'. Secondary damage from prolonged contact with approach light structure marked 'b'

Figure D

Left outboard leading edge flap damage caused by contact with approach lighting structure

Figure E

Figure F

Right inboard trailing edge flap, aft segment detached on water entry

Figure G

Left outboard trailing edge flap, aft outboard corner damaged by sea wall contact

Figure H

Left outer leading edge flap, lower edge scraped by contact with the sea wall

2. **Landing Gear**

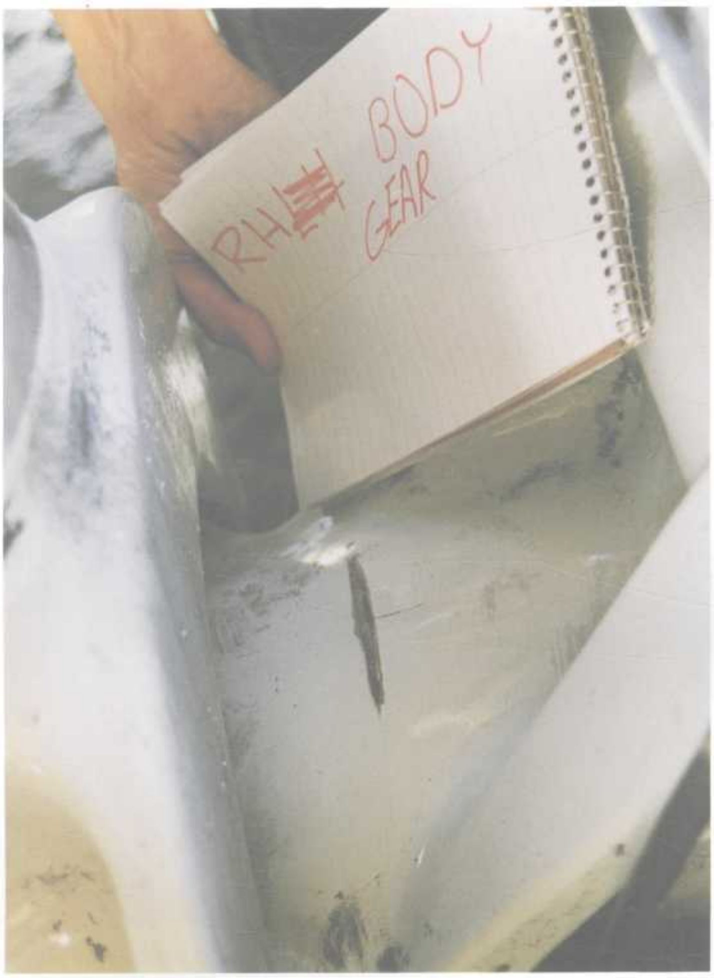
During the period the aircraft was in the water, divers from the salvage company were able to assess that all landing gears were down and were able to insert ground lock pins into both wing landing gears. Once recovered, both body gears were also so secured but it was not possible to lock down the nose gear due to slight structural distortion in this area. Later examination of the landing gear revealed it to be in relatively good structural condition but it was apparent that both body gear trucks had over travelled in a leading wheel down sense such that hard contact had been made between the truck and the oleo strut. Longitudinal cracks on both trucks ran from the areas of contact, reference **Figures I and J**. With the aircraft's weight partially supported on jacks, main gear oleo pressures and extensions were recorded as follows :-

LWG	Extension	-	25.5"	Pressure	-	750 psi
LBG	Extension	-	22.75"	Pressure	-	550 psi
RBG	Extension	-	22.6"	Pressure	-	600 psi
RWG	Extension	-	24.5"	Pressure	-	800 psi
NG	Deflated during salvage operation					

There was no indication of leakage from any of the oleo seals.

The landing gear operating system was not examined in detail but it was apparent from the successful landing and rollout that it had worked correctly prior to the accident. All main and nose gear doors were closed at the time of the accident. All truck tilt proximity switches (8 in total) were removed and transported to Boeing for examination and, where appropriate, functional testing. Performance evaluation indicated that five of the sensors exhibited degraded performance due to the moisture ingestion.

Figure I



Damage areas on both body gear trucks as a result of overtravelling in a leading-wheel down sense as the aircraft rolled over the sea wall lip

Figure J

3. **Wheels and Tyres**

After the aircraft had been recovered to the airport bridge, and before it was towed to the parking area, an initial examination of the wheels and tyres was made. There was no apparent damage to any of the wheels, apart from the effects of salt water corrosion, and it was established that each one was free to turn. All tyre pressures were confirmed as essentially correct and the pre-accident condition of the tyres was judged to be acceptable and consistent with normal usage. Several tyres, however, were at, or close to, their wear limits. There was no evidence that any of the tyres had suffered locked wheel or reverted rubber skidding. On all tyres there were cuts and abrasions associated with their passage over the relatively rough ground adjacent to the sea wall and into the water. Several main gear tyres exhibited patches of small chevron shaped cuts on the tread surface, said to be indicative of heavy braking. This was observed on the tyres of several other 747 aircraft examined, but not to the same level. Transverse abrasion lines were present on most of the tyres, but particularly so on the nose gear tyres. This was consistent with the aircraft sliding slightly to be right with the wheels rolling (approximately 15 degrees maximum yaw angle to the left) prior to leaving the paved surface. A large nose wheel steering angle to the left, deduced from the runway marks (70 deg. is the possible maximum), accounted for the more severe transverse abrasion present on both nose wheel tyres.

Wheels were removed at two locations which enabled a visual inspection to be carried out of two sample carbon brake packs. Following a strip examination at HAECO both units were seen to be in good condition, with acceptable wear patterns, and still to be within limits for a new set of brakes. The aircraft had recorded 359 landings from new up to the time of the accident.

4. Primary Flight Control Systems

Evidence from the DFDR, and the crew, both indicated that all the flight controls had operated normally throughout the flight and landing. Therefore, examination of the elevator, aileron and rudder control systems was limited to a simple visual check to confirm circuit continuity from the cockpit controls to the hydraulic actuators at the various control surfaces. This was not possible with the rudder circuit as the fin, rudder and associated mechanism were lost following removal of the fin by explosive means. With the above exception, integrity was confirmed, with all observed damage resulting from salt water immersion or the recovery. Aileron trim was established as being very close to neutral and pitch trim was set with the tail plane leading edge at mark 2 on the reference scale on the fuselage side.

5. Flaps

DFDR data indicated that flap selections throughout the flight had occurred at times consistent with normal operation of the aircraft. As found after the accident, the flap selector was in the flap 30 (full) gate, and all flap screw actuators were at full travel. A visual examination of the flap operating mechanisms, surfaces and fairings revealed only accident related damage. The aft section of the right inboard flap detached during the accident sequence, with some evidence to indicate that this may have been struck by the No. 3 engine as it broke away. The aft outermost corner of the left flaps had been damaged by contact with the sea wall.

6. **Power Plants**

The aircraft was fitted with four Pratt and Whitney PW-4056 Turbo Fan engines, the basic details of which are as follows :-

Position	Serial No.	Inst. Date	Total Hours	Total Cycles
No. 1	727324	8 June 93	1969:34	359
No. 2	727325	8 June 93	1969:34	359
No. 3	727322	8 June 93	1969:34	359
No. 4	724316	16 Sept 93	6538:37	1133

In general, it was apparent that all four engines were at a low power condition at the time of their entry into the water, with little deformation of their fan sections being apparent. All external damage seen was consistent with contact with the sea wall, water entry, an extended period of contact with lighting structures/rocks and salvage damage. It was evident that the thrust reverser systems were stowed on all four engines and that there had not been of any major failure of rotating components or casings prior to the accident. The engines damage are shown and described in figure K to S. Data from the DFDR supported the view that the engines had been operating normally during the flight and landing, including the selection, and cancellation of, reverse thrust between 22 and 5 seconds before the aircraft contacted the water. Retraction of the wing inboard and mid span leading edge flaps is commanded automatically on reverse thrust selection, these flaps re-deploying after a 5 second delay following thrust reverse cancellation. The aircraft came to rest with the inner and mid span leading edge flaps fully retracted but with the outboard flaps extended.

Figure K

ENGINE No 1

Figure L

ENGINE No 2

Engines 1 and 2 fans showing evidence of low power condition at water entry, consistent with DFDR data

Figure M

ENGINE No 3

Figure N

ENGINE No 4

Engines 3 and 4 showing evidence of low power condition at water entry, consistent with DFDR data.

Figure O ENGINE No 4

Figure P ENGINE No 3

Figure Q ENGINE No 3

No 4 engine details showing effect of engine rear mount deformation due to strike on sea wall. Fan and turbine exit areas for engine No 3 are also shown, which identify no evidence of pre-impact damage and stowed thrust reverse blocker doors. All engines were similar in this respect.

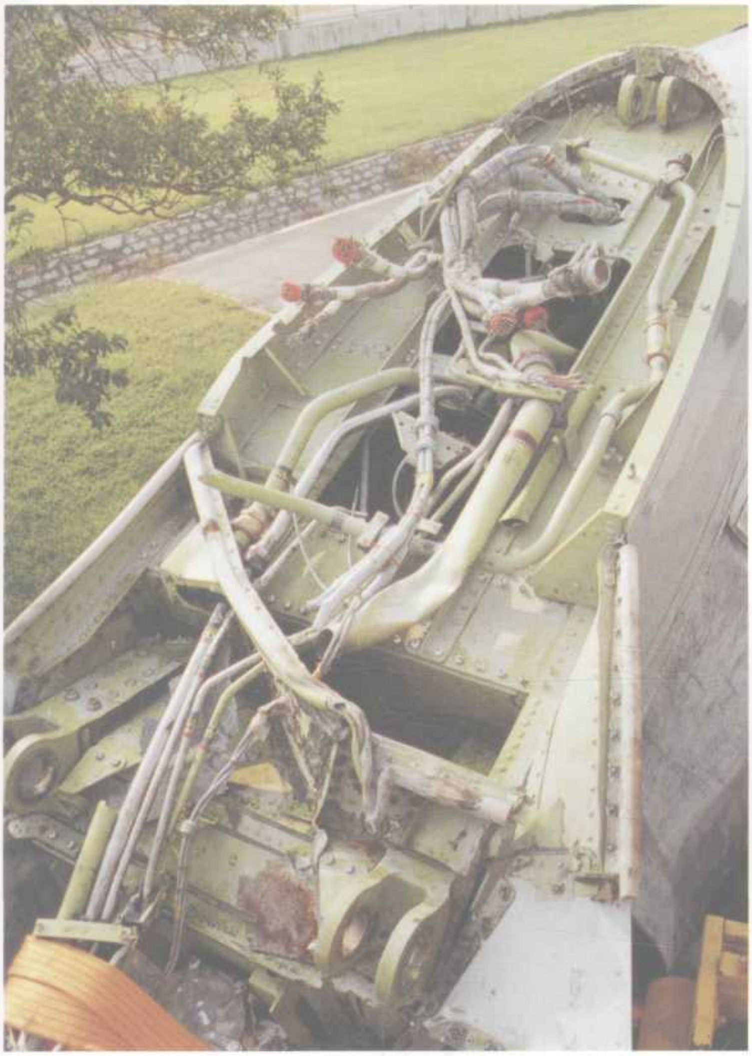


Figure R

Details of Engine No 3 strut separation from the wing by fuse pin failure. The wing structural box remained intact.

Figure S

Details of No 4 engine strut failure. The engine was first to enter the water, at approximately 30 kts, with the aircraft yawed left by some 15 degrees. The wing structural box remained intact.

7. Hydraulic System

The four hydraulic systems on this aircraft were not examined in detail, as the DFDR data and information from crew interviews indicated that there had not been any problems with these systems. All major services, for example, the primary flight controls, flaps, speedbrakes, wheel brakes and landing gear operating systems, appeared to have functioned correctly when selected. The hardware of these systems was visually examined during testing/examination of other areas of interest in the aircraft with no pre-accident defects being identified. The return line filters from each system were, however, removed and examined. All were found in good condition and free from any significant metallic contamination.

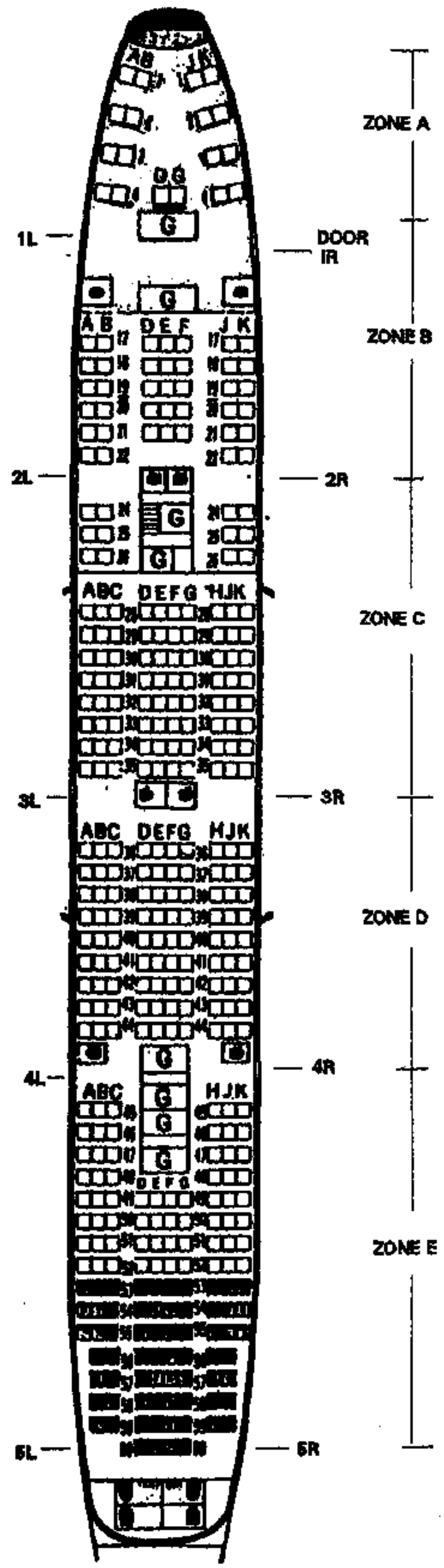
8. Fuel System

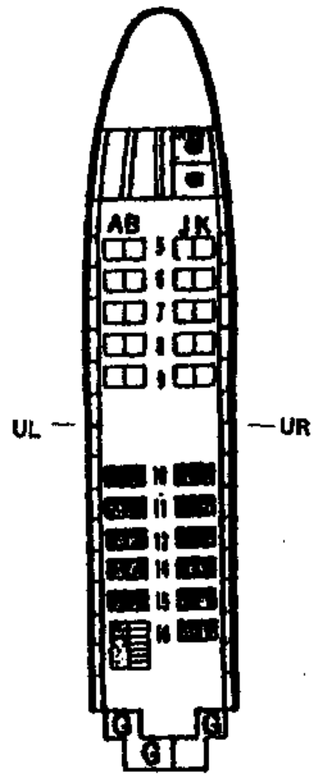
The fuel system was not examined. Data from the DFDR, engine parameters in particular, showed all four engines to be operating as expected throughout the flight. Work has been carried out by Boeing in respect of fuel flows versus thrust lever angle for the period from touchdown. Preliminary data indicates the fuel flow was consistent with other engine parameters during the approach and landing. No abnormalities were recorded or reported with respect to fuel or lack of demanded power throughout the flight. Significant quantities of fuel were removed from the wing tanks during the recovery operation and samples have been sent for analysis. This revealed all samples to essentially conform to the specification for Jet A-1 fuel, with only minor deviations being identified. These were thought to have resulted from contamination after the accident and/or from the sample storage conditions.

9. **Electrical Generation/Distribution Systems**

There was no evidence from the DFDR, CVR, CMC's or crew of any electrical system malfunction on this aircraft up until the time that it received damage in departing the end of the runway. During the examination of the aircraft generally, no evidence was seen of any defect or unusual condition relating to the electrical systems.

CABIN LAYOUT OF THE AIRCRAFT





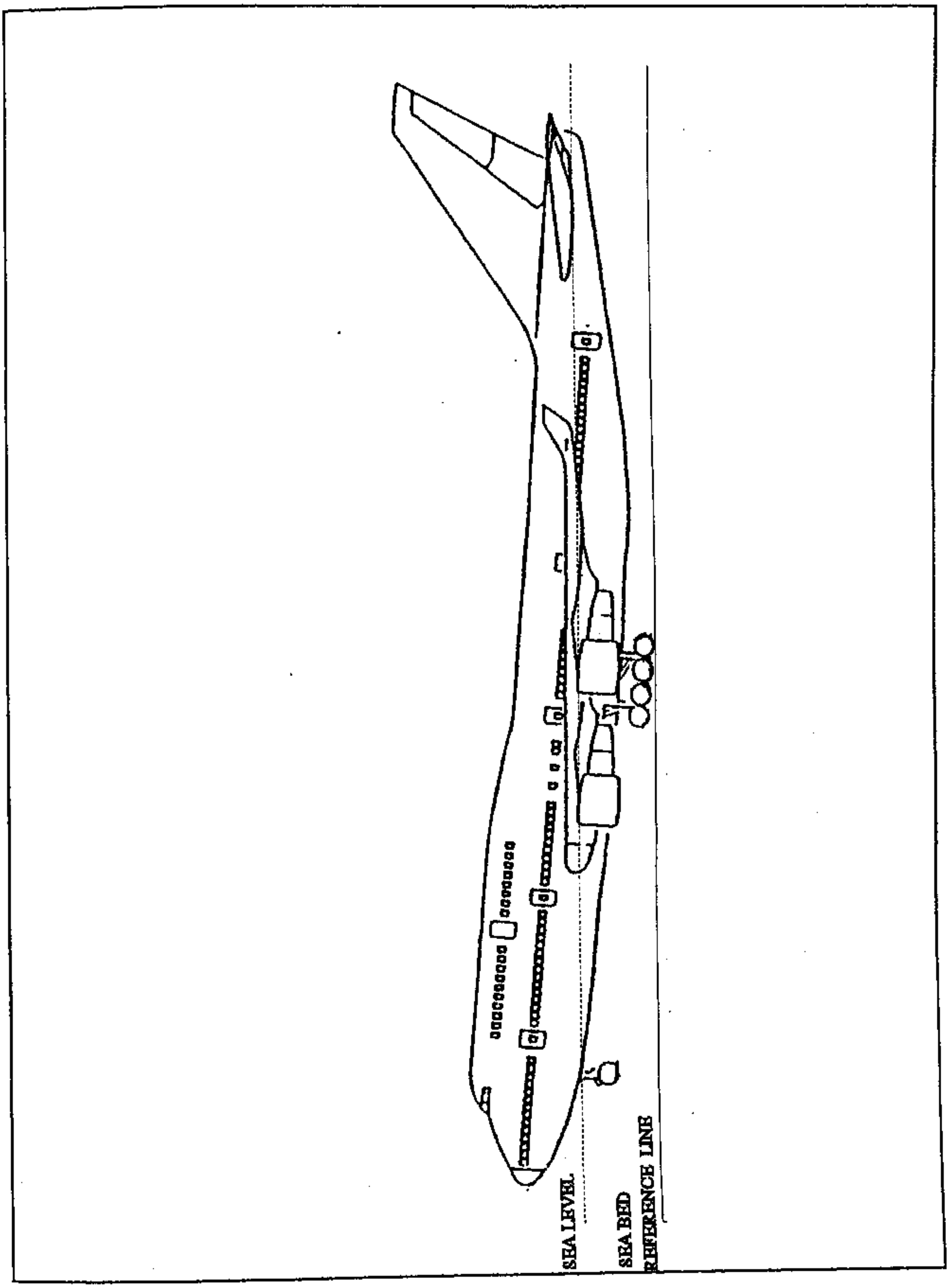
Upper Deck

Configuration

First Class : 18 Seats
Business Class : 93 Seats
Economy Class : 300 Seats

ATTITUDE OF THE ACCIDENT AIRCRAFT IN THE SEA

(AFTER EVACUATION COMPLETED)



Damage to the aircraft first class section

CAL 605 Aircraft Accident

Rescue Operations

AIRCRAFT MECHANICAL SYSTEM TESTS

1 Speedbrake system

The speedbrake system was physically examined in some detail. Due to the nature of this accident, however, it could not be tested as a complete system because this required both electrical and hydraulic power. Therefore, a visual inspection and functional tests, where possible, were carried out to confirm the correct operation of its components parts, or sections.

Mechanical integrity of the complete system was established from the cockpit lever through to the inputs of hydraulic valves on each spoiler actuator in the wings. There was no evidence that the circuit had jammed and there were no disconnections apparent. With the exception of the two innermost spoiler panels on each wing (5 to 8), which were not tested at this time, all actuators (except No 11) functioned satisfactorily when hydraulic pressure was applied individually from a handpump with their input levers operated by hand.

Spoiler actuator No 11 was re-examined and removed to a hydraulic test facility. Here it was shown to operate correctly, however hydraulic pressure in excess of 1000 psi inlet pressure was required to unlock the unit. Thereafter the unit worked at a significantly lower pressure. Spoiler panel 11 had been damaged during the aircraft recovery by the support ropes for No 4 engine which, from the damage, appeared to have imparted a high down load to the actuator. This may have influenced the initial test. Spoiler actuators Nos 5 to 8 were also tested on the aircraft at a later time. These actuators required multiple hydraulic pressure inputs which were supplied from a handpump rig. All actuators operated correctly.

The mechanical operation of the speedbrake lever mechanism in the cockpit was satisfactory as was the mechanical and electrical operation of the arming switch S217, and reverse thrust sensing switch S861 on levers 2 and 4. Electrical power was applied to the actuator motor via the P6 electrical panel in the cockpit. This motor operated smoothly, and without hesitation, in both directions over many test cycles. This test also confirmed that upon retraction, the lever would drop into the down detent and therefore cease to be armed. It was also shown at this time that operation of thrust reverse levers 2 or 4 would correctly lift the lever out of the down detent and arm the speedbrake system The above testing also confirmed the integrity of the interconnecting control wiring associated with this system in the cockpit.

The relays associated with this system, R7519, R7520, and R834 to R838, were removed from the aircraft and subjected to individual testing. All relays were within normal specification with respect to pick up and drop out voltage, coil current and resistance, contact millivolt drop at 10 amp load and insulation and dielectric tests.

2 Wheel Brakes

The nature of the accident precluded any meaningful functional testing of all but a few components, such as the brake packs, pedals and autobrake selector switch, all of which were shown to be serviceable.

3 Thrust Control

3.1 Thrust Lever Angle (TLA) Measurements

Of significance were the switches S1B to S4B, operated by thrust levers 1 to 4 respectively, which provided inputs to the following aircraft systems:-

S1B Autobrake and auto speedbrake

S2B Autobrake

S3B Autobrake and auto speedbrake

S4B Autobrake

Each switch should be set to operate at a TLA of 8° (+/- 1°) from the idle (thrust levers aft) position. Measurements of TLA for each switch operating point were made on B-165 two days after the accident, as follows:-

S1B	TLA increasing	8 deg 10 min
	TLA decreasing	7 deg 10 min
S2B	TLA increasing	10 deg 00 min
	TLA decreasing	7 deg 30 min
S3B	TLA increasing	8 deg 30 min
	TLA decreasing	7 deg 40 min
S4B	TLA increasing	8 deg 30 min
	TLA decreasing	7 deg 20 min

In addition to the above, switches S1B to S4B were satisfactorily checked for correct electrical operation and the switch pack containing these switches was examined and found to be secure.

After the aircraft had been recovered from the water the force required to move each thrust lever was measured normal to the lever axis, each one requiring between 4.5 to 5 lbf to move in either direction over the idle to 10° position. (Similar movements on a flight ready B747-400 required forces of between 2 and 3 lbf). Data supplied by Boeing indicated maximum loads of 2 lbf when increasing power, 3 lbf when decreasing. However, it was noted that after a period of time in the humid, salt water induced, corrosive cockpit environment, the thrust levers became progressively more stiff and required exercising to minimise their operating loads. Boeing were asked about the possibility of vibration-induced uncommanded throttle movements. It transpired that no vibration testing had ever been carried out on the thrust levers, but also that no reports had been received of any uncommanded lever movement for any reason.

The thrust levers on this aircraft signal the engine control units, EECs, by electrical means, not mechanical cables. Thrust lever angle is sensed by a resolver, one linked to each lever, mounted beneath the pedestal. This linkage was examined and found free to move, with all joints in the system secure (ie, no backlash). By exciting each resolver from a 6 volt RMS source, measurements were made of the resolver outputs for idle (0 degrees), 3.5 units (degrees) forward and full thrust (50 degrees) positions of the levers. The above data was passed to Boeing for analysis. Boeing have confirmed that these values are all nominal and that, in the absence of any relevant faults stored in the CMC's, the thrust lever resolvers were sending valid signals to the EEC's at the engines.

3.2 Reverse Thrust Control

Correct mechanical operation of the reverse thrust levers was established, as was correct electrical operation of the reverse thrust switch S861 on levers 2 and 4. The electro-mechanical interlocks in the pedestal, which restrict full movement of these levers and prevent reverse thrust from being developed until the reverse thrust cowls have translated open on each engine, were electrically functioned, and their interlock function checked. All four operated correctly, allowing full reverse thrust to be selected on the levers (89.25 degrees of movement) once the actuators had extended. The relays which drive these actuators, R7640 to R7643, were removed and tested satisfactorily.

3.3 Autothrottle

The autothrottle mechanism in the cockpit pedestal is driven from a reversible three phase motor, commanded by the flight management system. The motor drives into a right angled gearbox, the output shaft of which runs across the pedestal and forms the axis about which the thrust levers rotate. The levers are coupled to this shaft by brake units which may be overcome easily by hand loads. Testing of the complete system was not possible due to the nature of the accident but examination of the cockpit mechanism revealed the motor to have seized as a result of corrosion. After cleaning, it operated normally and all four levers were demonstrated to move together under the influence of this motor in both directions over their full range. Thrust lever breakout hand loads were higher than normal, at 4.5 to 5 lbf but this was attributable to the effects of slight corrosion. Examination of the DFDR data showed the autothrottle to have been disengaged during the approach and that it had re-armed upon landing, which is normal. There was no indication that it had re-engaged during the rollout.

4 Windshields/Wipers/Rain Repellent System

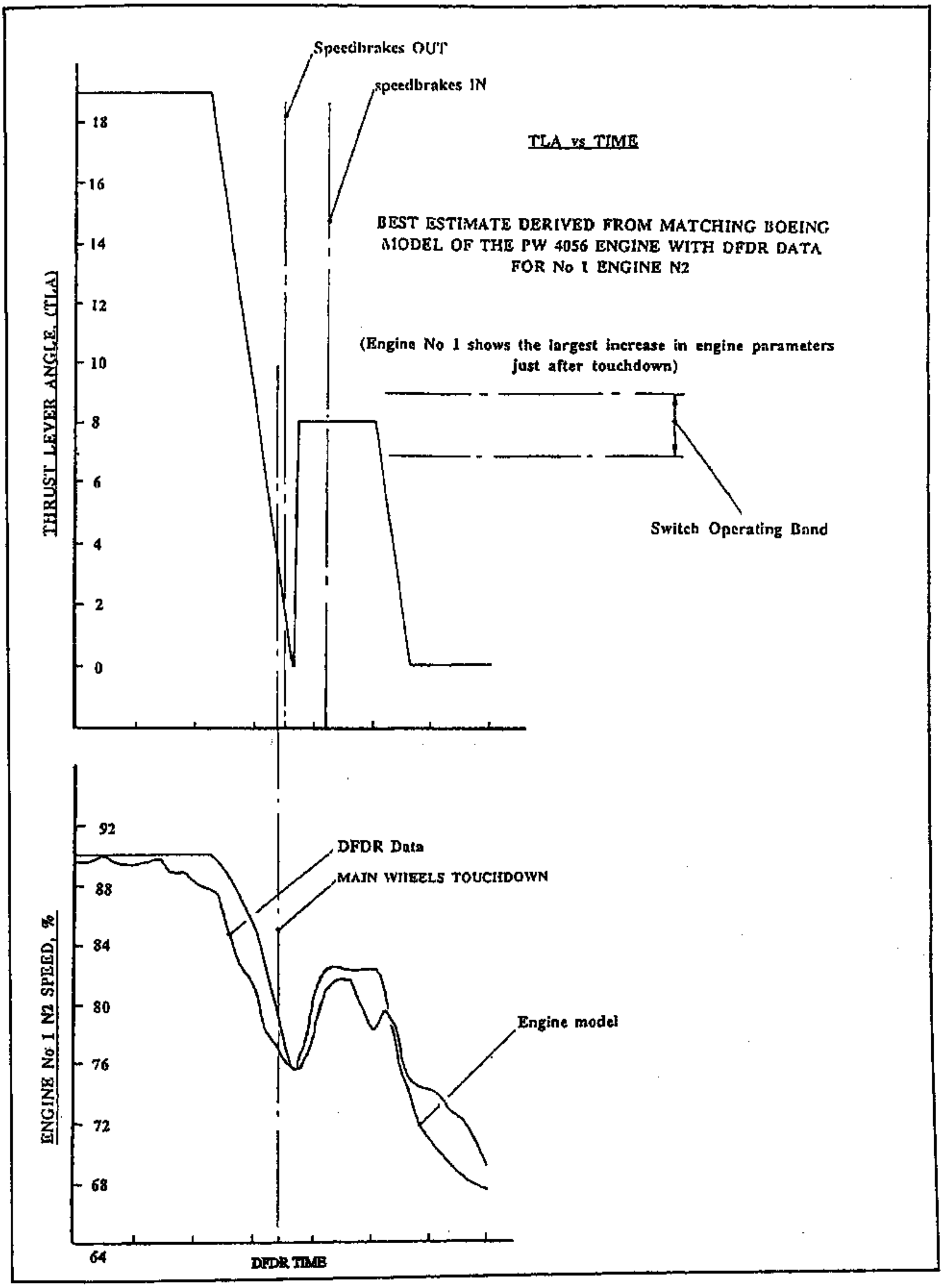
Examination of the windscreens on B-165 revealed both to be in excellent condition. There were no visible scratches and the only deposits were as a result of this area being splashed with sea water whilst the aircraft had been in the water. Neither wiper blade was in the parked position which suggested that they had both been operating as the aircraft entered the water. Examination of these blades showed both to be in good condition and both wiper arms had been adjusted such that the blades were in firm contact with the windshields. The RainBoe rain repellent system was examined. The fluid reservoir bottle was found to be full and the check valve/selector switch was found in the horizontal position. Electrical power was applied to the system and upon pressing the appropriate buttons, it functioned satisfactorily, discharging fluid for approximately 0.5 sec onto each windshield. This test was also done with the selector in the vertical position; there was no detectable difference in the operation of the system. Both wiper blades were removed and sent to Boeing for analysis, with the intention of establishing whether RainBoe residue was present on the blade rubbers from prior usage of the system. The analysis stated:

> *"Although the presence of titanium with silicon may be an indication of RainBoe residue, the presence of other elements whose sources are unknown made it impossible to conclusively identify the sample as containing RainBoe residue."*

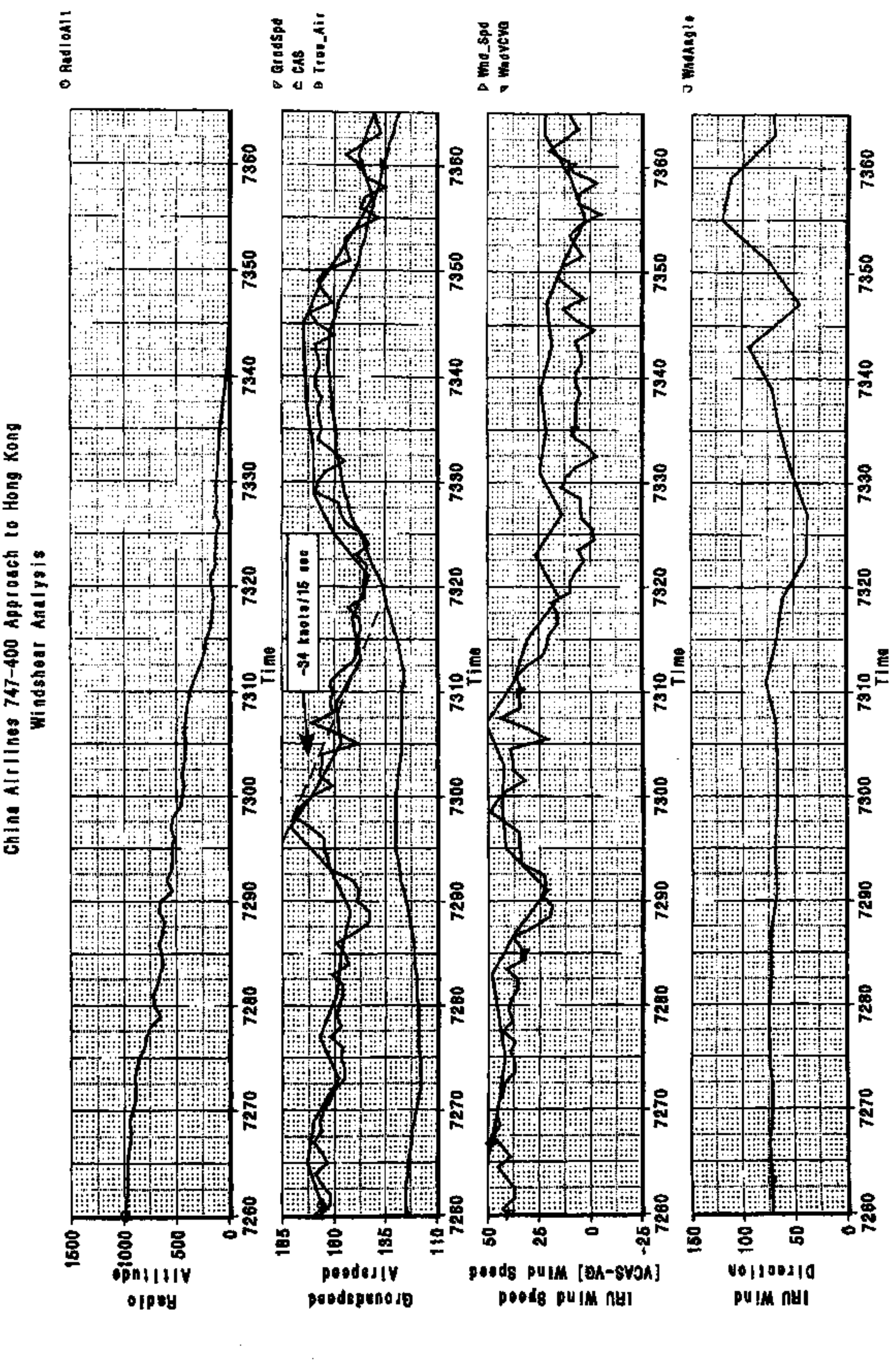
Nose Gear Steering System

The fact that the aircraft had accomplished a successful landing, and had essentially tracked the runway heading in a gusting crosswind to near the end of the runway, strongly indicated that the aircraft's nose and body gear steering mechanisms had been serviceable prior to the accident. However, functional checks were made on the nose gear system by applying hydraulic pressure at the steering actuators control valve. By doing this, and operating the input from the cockpit tillers input to the nose gear, it could be functioned smoothly from one extreme of travel to the other. Control cable continuity from the tillers was established although the right side cable had failed as a result of overload during the accident or aircraft recovery.

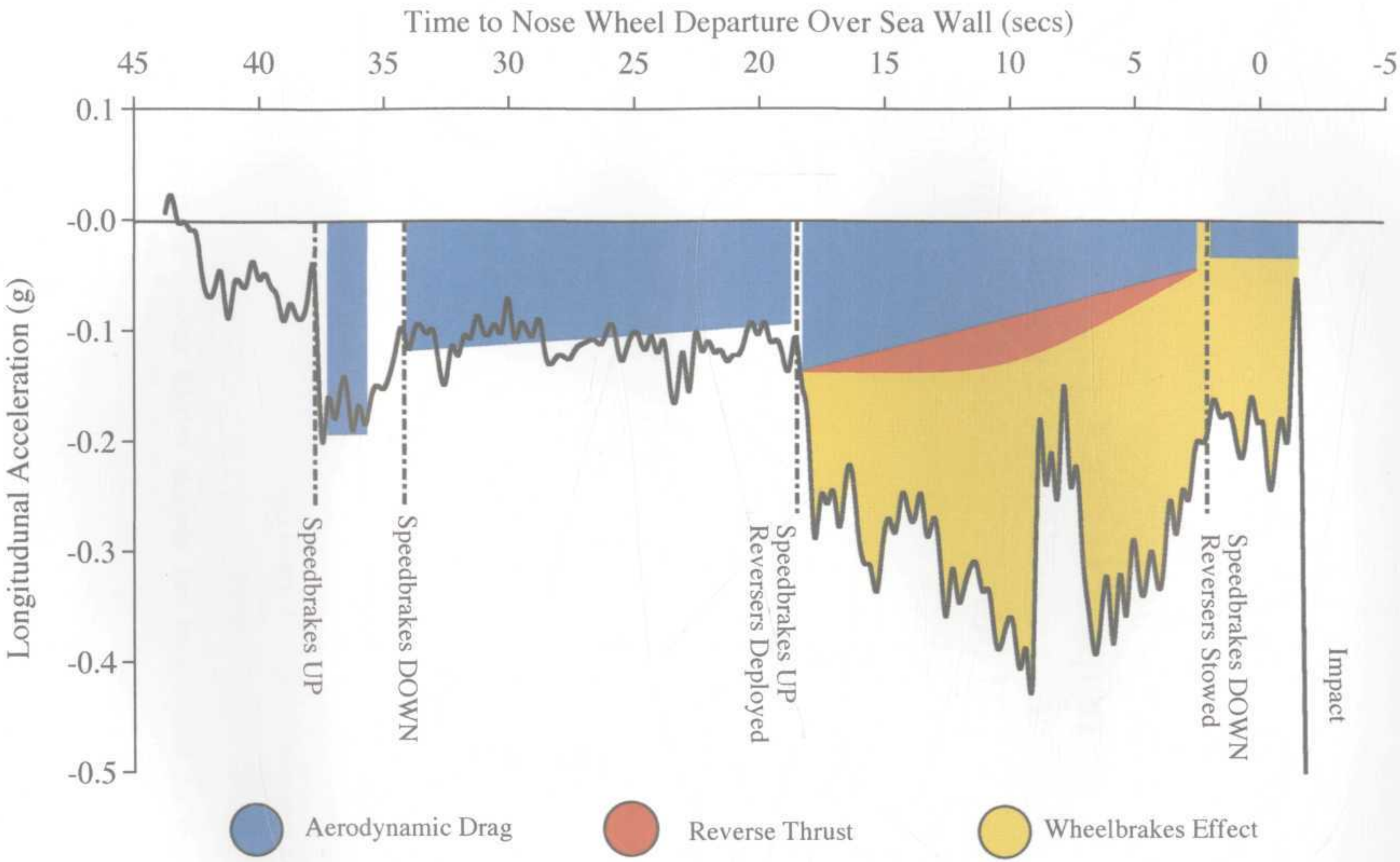
N2 response of a PW 4056 engine (computer) model to thrust lever movement input



Graphs depicting the windshear event



Elements contributing to the deceleration of the aircraft during rollout



B-165 MEASURED LONGITUDINAL ACCELERATION BREAKDOWN DURING ROLLOUT

Extracts of Report on Runway Friction Analysis Hong Kong Kai Tak Airport Runway 13/31 following the accident to Boeing 747-400 B-165 on 04 November 1993

by I Beaty, College of Aeronautics,Cranfield

(<u>Note</u>: The full report on runway friction analysis has been copied to the State of Registry/Operator and Boeing for reference.)

Summary

Following the accident to Boeing 747-400 B-165 on 04 November 1993 at Hong Kong Airport a runway friction classification was performed in accordance with ICAO Annex 14 Mu-Meter method 2 requirements. Because of the tow vehicle's inability to achieve the required speed of 130km/h (80mph) the trial was performed at 96km/h (60mph) and a correction was applied to the results. The average 96km/h (60mph) reading was 0.60, which equates to a 130km/h (80mph) reading of 0.55. ICAO Annex 14 defines the Design Objective to be 0.65 and the Maintenance Planning Level to be 0.45. Rubber deposits along the full length of the runway are a major problem and the Airport Authorities operate a rubber removal plan which is of great benefit to the friction characteristics of the runway.

Contents

1. Introduction

1.1 This report describes a runway friction calibration carried out on 13/31 Runway at Hong Kong Kai Tak Airport on 04 November 1993 by the Aircraft Ground Operations Group (AGOG) of Cranfield University. The calibration was requested by the Hong Kong airport authorities at the instigation of the UK Air Accidents Investigation Branch following an accident involving a Boeing 747-400 which slid off the end of the runway into the water.

1.2 Table 1 below shows the recommended Mu-Meter readings for a runway surface as defined in ICAO Annex 14.

Test equipment	Design objective for new runway surface	Maintenance planning level	Test water depth (mm)	Test speed (km/h)
Mu-Meter method 2	0.65	0.45	0.5	130

Table 1 ICAO recommended Mu-Meter readings

1.3 Runway friction calibrations to ICAO standards are performed using the Mu-Meter which has a continuous trace output and the capability of depositing water beneath the measuring wheels to simulate natural wet conditions.

1.4 The single wet calibration reading is normally obtained from the average of four runs at 130km/h (80mph) adjacent to the centreline (in the area most trafficked by aircraft main wheels) with 0.5mm water depth deposited beneath the Mu-Meter measuring wheels. However because the tow vehicle used for these trials (Fig 1) was not capable of achieving the required towing speed, the tests were performed at the reduced speed of 96km/h (60mph) and a correction factor applied, see Attachment. Other Mu-Meter runs were carried out at various speeds (still with 0.5mm water beneath the wheels) in order to establish a speed/friction curve for the runway.

1.5 A National Runway Friction Program carried out in the United States several years ago also used the Mu-Meter but with an increased water depth of 1.0mm beneath the wheels and a reduced speed of 65km/h (40mph). A run under similar conditions was added to this trial to apply a further correction based on runs performed on all UK runways (see Attachment).

2. Runway Description

2.1 Runway 13/31 is 3393 metres long and 61 metres wide. The surface is grooved asphalt with groove size 3mm x 3mm at a 60mm pitch. Figs 2 and 3 are close-ups of typical areas of the grooved surface close to the centreline.

2.2 Research in the United States in the early 1970's showed that the ideal groove size for high friction and good drainage was 6mm x 6mm at 25mm pitch. However the 6mm groove proved expensive to cut and a compromise 3mm groove was recommended (still at the same pitch), the performance of which was not greatly degraded from that of the 6mm groove.

Most grooved UK runways conform to this standard, the one known exception being Aberdeen which has 3mm x 3mm grooves at a 50mm pitch. When the new Aberdeen runway was first tested in 1988 the friction value was 0.54 due to the lack of micro-texture on the heavily rolled Asphalt between the grooves. When a follow-up friction calibration was performed in 1992 weathering and trafficking of the surface had improved the micro-texture considerably with the consequence that the friction value had increased to 0.69. It is likely that the same effect will be seen on the Hong Kong runway.

2.2 During runway construction the groove width was specified to be between 4.5mm and 6.5mm. The majority of the grooving appears to be at the lower width and in some cases (Fig 6) was even lower than this. Similarly, though the groove spacing was specified to be between 50mm and 60mm, the majority was at the wider spacing. The effect of the grooving is diminished where rubber is deposited, causing a narrowing of the grooves. Some grooves have lost their sharp edges, Fig 7.

2.3 Rubber deposits on this runway were subjectively assessed as heavy. Photographs of the touchdown areas at 13 and 31 thresholds are shown in Figs 4 and 5 respectively.

2.4 The Hong Kong airport authorities operate a rubber removal plan which involves the progressive removal each night of an approximate 50m length of deposited rubber from the most heavily contaminated areas at each threshold. A chemical, AC70, is spread on the rubber, allowed to react and then removed using high pressure water. Removing the rubber from these areas has a beneficial effect on the friction of the runway as will be described later in this report.

3. Test Equipment

3.1 Mu-Meter

3.1.1 The Mu-Meter is the standard UK equipment for runway friction measurement. The machine used for these trials was Serial No. MLSL419, fitted with Dunlop RL2 tyres and owned by the Hong Kong airport authority (Fig 1). The Mu-Meter carried a self-wetting attachment capable of depositing a measured amount of water beneath the measuring wheels.

3.1.2 The friction measuring range of the Mu-Meter is from 0 to 1 with both analogue and digital readouts. Only the primary analogue output was used in these trials. The calibration of the machine ensures that readings on a dry runway surface are in the region of 0.8 and consequently readings on a wet surface should be lower than this figure.

3.2 GripTester

3.2.1 The GripTester is a new friction measuring device which like the Mu-Meter is towed at 65km/h (40mph) behind a vehicle suitably equipped to deposit a measured amount of water beneath the measuring tyre. The Cranfield University GripTester Ser. No. 001 was taken to Hong Kong as a back up against the possibility that the Hong Kong Mu-Meter was unserviceable. In the event the Hong Kong machine was useable and although some runs were made with the GripTester, the Mu-Meter was treated as the primary measuring device.

3.2 Tow Vehicle

3.2.1 The tow vehicle was a Ford Falcon saloon, Fig 1. The car was modified to carry a flexible water tank and pump to supply water to the self-wetting system on the Mu-Meter. The vehicle was incapable of achieving the ICAO required test speed of 130km/h (80mph) and so the tests were carried out at 96km/h (60mph) and a correction applied to the results

4. Test Procedure

4.1 Calibration

4.1.1 Mu-Meter calibration was carried out in accordance with the manufacturer's handbook, which entails manually pulling the machine over a 1m long test board and achieving a reading of 0.77. Normally the tolerance is ±0.03, however for this trial the tolerance band was reduced so that calibration was only accepted between the readings 0.765 and 0.775, a tolerance of ±0.005. As a confirmation of the calibration it was expected that the Mu-Meter runs on a dry runway at 65km/h (40mph) would be in the range 0.78 to 0.82.

4.1.2 Calibration of the self-wetting system was carried out prior to the trial to ensure that at each of the test speeds 0.5mm water depth was deposited beneath the measuring wheels (with the exception of Run 11, see Para 4.2.1.5).

4.2 Trials

4.2.1 Thirteen runs were performed with the Mu-Meter along the full length of the runway, in the following sequence:

4.2.1.1 One run at 65km/h (40mph) without self-wetting as a 'dry' Mu-Meter calibration run close to the runway centre line; however the runway surface was damp at this time due to rainfall.

4.2.1.2 Four runs at 96km/h (60mph) with self-wetting, one in each direction both sides of the centreline spaced approximately 3 and 4 metres from the centreline.

4.2.1.3 One run at 96km/h (60mph) with self-wetting approximately 10m from the centreline traversing the touchdown zone and fixed distance markers.

4.2.1.4 Two runs at each of the speeds 32, & 65km/h (40mph) approximately 3m from the centreline. Water flow rates were adjusted for each speed to maintain 0.5mm water depth beneath the Mu-Meter measuring wheels.

4.2.1.5 One run at 65km/h (40mph) 4m from the centreline, with a maximum water flow rate (equivalent to 1.0mm water depth at this speed). This run was performed to enable a direct comparison to be made of UK and US methods of runway friction calibration.

4.2.1.6 One run at an angle across the runway following the tracks of the accident aircraft.

4.2.1.7 A final full-length 65km/h (40mph) run without self-wetting was made on the runway surface which had dried out during the course of the trial to ensure that the Mu-Meter calibration was within tolerance.

5. Results and Discussion

5.1 In Table 2 Runs 1 & 13 are dry runs, without the self-wetting system operating, to prove the calibration of the Mu-Meter. A correctly calibrated machine can be expected to give a reading within the range 0.78 to 0.82. At the beginning of the trial the surface was slightly damp with the resultant lower readings of Run 1 (average 0.76), especially at the rubber contaminated ends. The surface dried out during the trial to give an average reading of 0.80 at the end (Run 13).

5.2 The friction values which apply to the ICAO requirement shown in Table 1 are derived from the averages of the four runs made adjacent to the centreline at 96km/h (60mph) (Runs 2 to 5, Figs 13 to 16 respectively). Each trace shows the full length of the runway from stopbar to stopbar. For analysis purposes the trace is divided lengthways into thirds as shown and an average determined by equalising the area above the line with the area below. The results for each third are shown in Table 2. The final calibration figure is the average of these third readings for Runs 2 to 5 at 96km/h (60mph), which in this case is 0.60. This value has been converted for use in Table 1 to an equivalent 130km/h (80mph) value of 0.55 by applying the correction in Ref 1, page 17 of which is reproduced at Appendix B, page 1 of this Report.

5.3 Although the average friction reading of Runs 2 to 5 is 0.60 it can be seen from the traces that there is some variability along the length of the runway. The higher values occur at the centre point of the runway where less rubber has been deposited, and also in the areas where rubber has been removed. The lowest values are generally at each end of the rubber removal area and it is therefore suggested that the area covered by the scheme is extended and the results monitored using the Mu-Meter with the self-wetting in operation. Low values can also be seen on the runway markings. It should be noted that these have not been included in the overall average of Para 5.2. By studying the traces it can be seen that without the rubber removal plan the trend would be for the touchdown areas to fall below the 0.4 (promulgation slippery when wet) value. The lengths of runway between the runway end and the threshold bars where there is very little aircraft activity give an average friction reading in the order of 0.70 (equivalent to 0.63 at 80mph).

5.4 Further runs (9 & 10) were made at 65km/h (40mph) with a calculated water depth of 0.5mm of water beneath the measuring wheels, the results of which give an average friction value of 0.63. By applying the correction factor from the graph shown in Appendix B, page 2 an equivalent 130km/h (80mph) value of 0.57 is obtained. The graph of Appendix B is a summary of the results of friction classification surveys of all UK runways by Cranfield over the past 13 years.

5.5 A single run (Run 11) was made at 65km/h (40mph) using the full capacity of the self-wetting system (equivalent to 1.00mm water depth beneath the measuring tyres) which gave an average friction reading of 0.61. By applying the correction factor from the graph shown in Appendix B, page 3 an equivalent 130km/h (80mph) value of 0.57 is obtained. The data for this graph was gathered as explained in Para 5.4.

5.6 A single run (Run 6, Fig 17) was made on the western side of the runway which traversed all the painted fixed distance markers. It was noted that the friction values of some of these markers was very low (falling to 0.06 in places). It is strongly recommended that an anti-skid paint is used for all runway markings, including the centreline.

5.7 A short run (Run 12) was made to investigate the friction values at the 31 threshold. The run was made at an angle across the runway following the tracks of the accident aircraft.

The run speed was 65km/h (40mph) with 0.5mm water depth beneath the tyres. Across the piano keys the friction value dropped below 0.10 followed by a rapid rise to 0.78 across the 50m of the diagonally grooved asphalt, Fig 8 reducing slightly to 0.70 on the final 100m of grooved concrete.

6. Conclusions

6.1 On Hong Kong Runway 13/31 the average friction reading adjacent to the centreline using the ICAO Mu-Meter method 2 (after correction for speed) is 0.55, which falls between the design standard for a new runway of 0.65 as defined in ICAO Annex 14 and the maintenance planning level at 0.45.

6.2 There is considerable variability of friction reading along the length of the runway (0.4 to 0.76),which is mainly associated with the deposition of rubber on the surface. The constant removal of rubber from the runway is an essential task for the maintenance of good friction values.

6.3 Experience with other similar runways indicates that as the runway surface wears and weathers the microtexture of the surface will increase and the overall friction value improve.

6.4 Painted markings cause the Mu-Meter readings when self-wetting runs at 96km/h (60mph) are performed to fall to 0.06 in some areas.

7. Recommendations

7.1 The runway friction calibration described in this report will identify low friction areas caused by poor surface texture, rubber deposits or other contaminants. Areas of low friction caused by standing water will not be identified. It is recommended that trials are performed during rainfall by airport personnel using the airport Friction Meter to obtain a friction survey across the full width of the runway. This procedure should be repeated at regular intervals in order build up a time profile of the state of the runway surface.

7.2 It is recommended that the rubber removal scheme is extended to cover more of the runway and that the results of this removal are monitored using the Mu-Meter with its self-wetting device in operation.

7.3 The runway markings should be repainted using a high friction paint finish.

8. References

8.1 R W Sugg, I Beaty and R J Nicholls. The friction classification of runways. S & T Memo 6/79. Defence Research Information Centre.

Airport: HONG KONG KAI TAK Rwy: 13/31

Date: 24.11.93	Time: 0300hrs
Condition: Damp	Length: 2740m
Surface Description: Grooved Asphalt	Width: 61m
Rubber Deposits: Heavy	
Weather: Occasional rain	

Run No	Dirn	Speed km/h	Dist from C/L	Self Wet	μ13	μCtr	μ31
1	13	65	1m E	Off	0.75	0.78	0.74
2	31	96	3m E	0.5mm	0.60	0.63	0.66*
3	13	96	4m E	0.5mm	0.64*	0.61	0.62
4	31	96	3m W	0.5mm	0.56	0.57	0.61*
5	13	96	4m W	0.5mm	0.56*	0.55	0.60
6	31	96	6m W	0.5mm	0.54	0.52	0.52*
7	13	32	3m W	0.5mm	0.67	0.70	0.66
8	31	32	3m W	0.5mm	0.67	0.68	0.67
9	13	65	3m E	0.5mm	0.63	0.63	0.61
10	31	65	5m W	0.5mm	0.62	0.64	0.65
11	13	65	4m E	1.0mm	0.62	0.60	0.61
12	13	65	Cross	0.5mm	0.08	0.78	0.70
13	31	65	1m E	Off	0.81	0.81	0.79

NB * - Not full third: vehicle accelerating.

Avg. 65km/h (40mph) dry reading: 0.80
Avg. 96km/h (60mph) self wet reading 0.60
Equiv. 130km/h (80mph) self-wet reading: 0.55
(Runs 2-5)

Table 2. Mu-Meter readings on runway 13/31

Fig 1 Mu-Meter and tow vehicle

Fig 2 Close-up of rubber contaminated grooved asphalt surface

Fig 3 Close-up of uncontaminated grooved asphalt surface

Fig 4 Rubber deposits at 13 threshold

Fig 5 Rubber deposits at 31 threshold

Fig 6 Narrow grooves

Fig 7 Close-up of worn grooves

Fig 8 Cross grooving near the 31 threshold

Fig 9 Effects of rubber removal

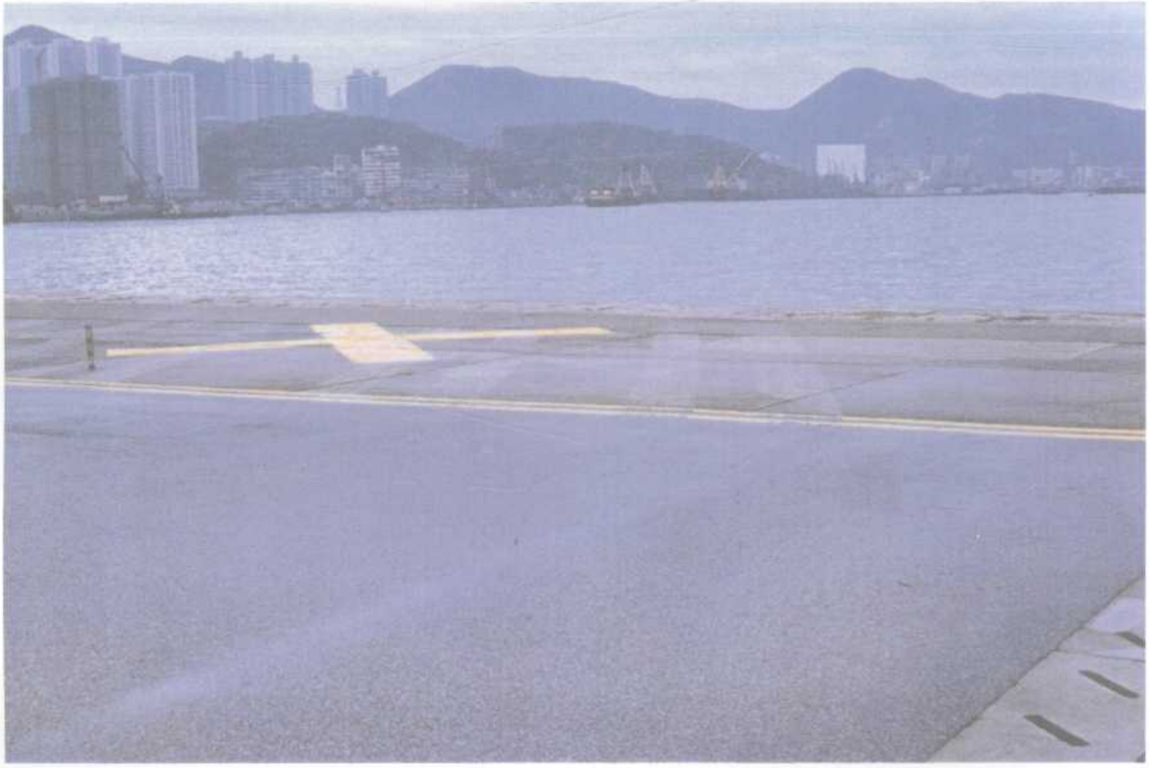


Fig 10 Tracks of aircraft entering water

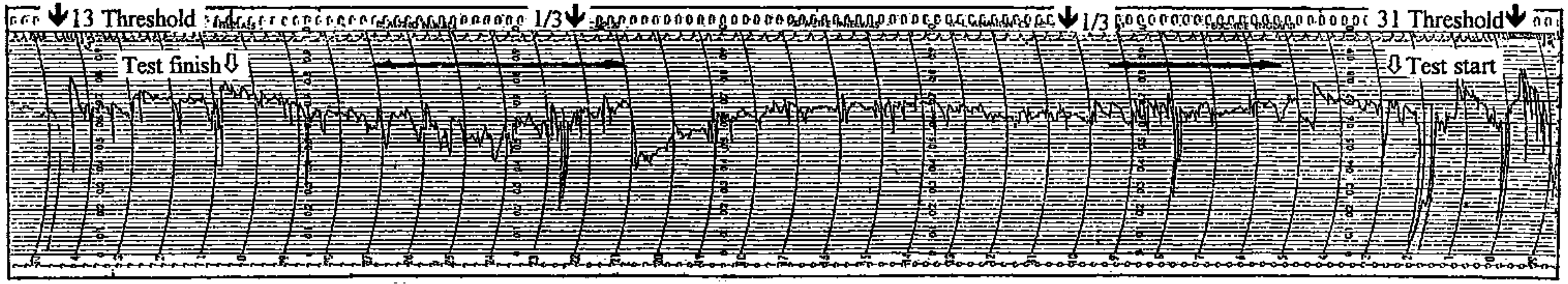


Fig 11 Run 2 3m E of c/l Vehicle speed 96km/h

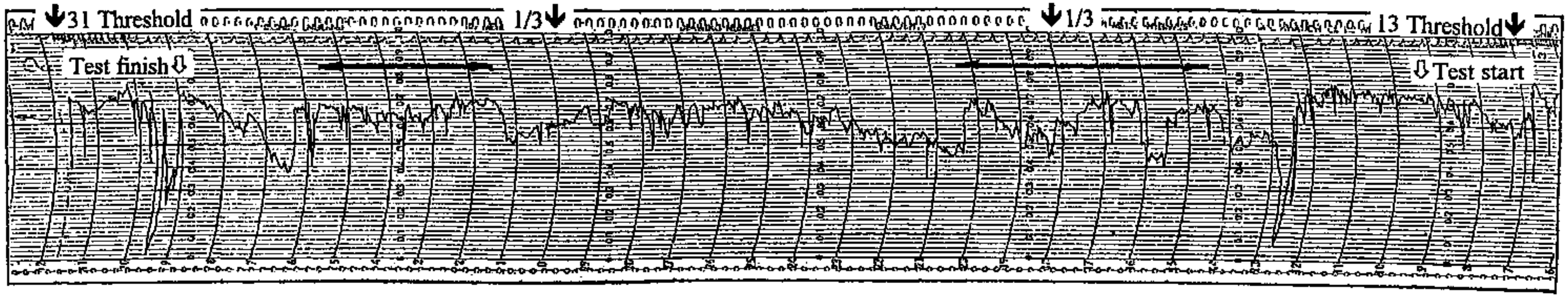


Fig 12 Run 3 4m E of c/l Vehicle speed 96km/h

Marked areas indicate rubber removal sites

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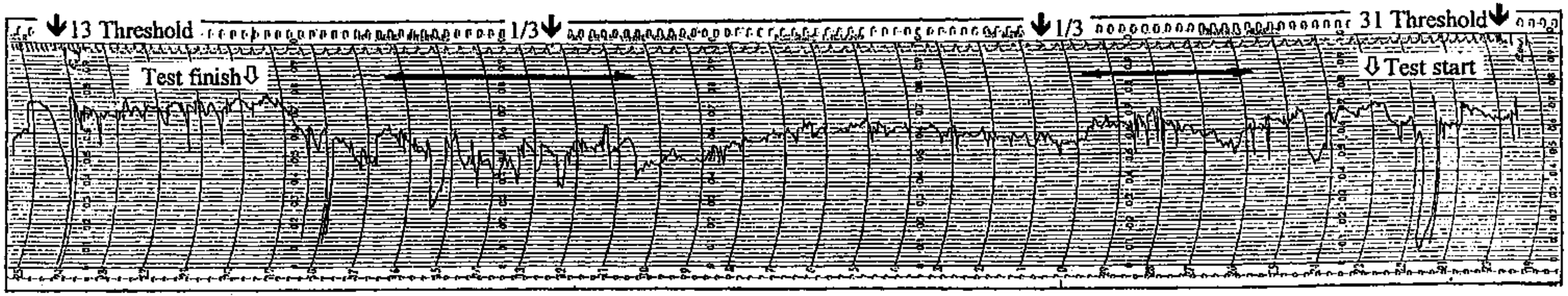

Fig 13 Run 4 3m W of c/l Vehicle speed 96km/h

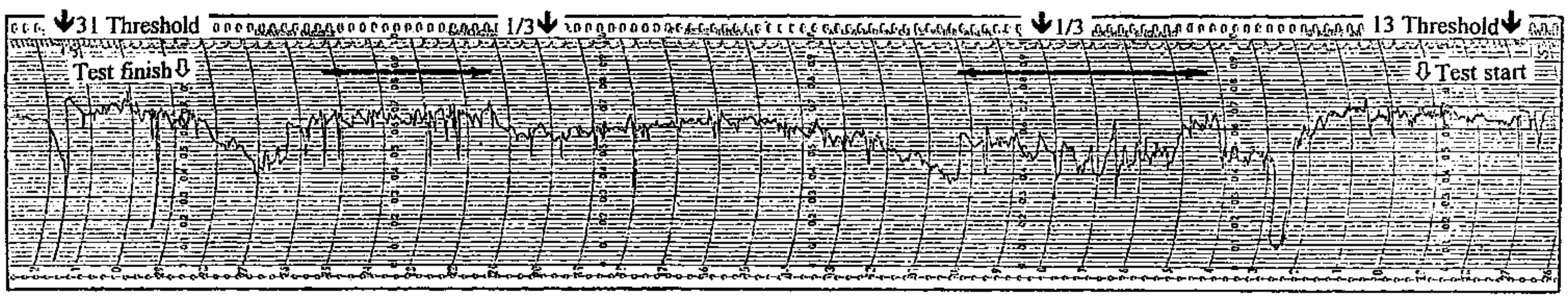

Fig 14 Run 5 4m W of c/l Vehicle speed 96km/h

Marked areas indicate rubber removal sites a - Threshold bars   b - Touchdown zone marker   c - Fixed distance marker

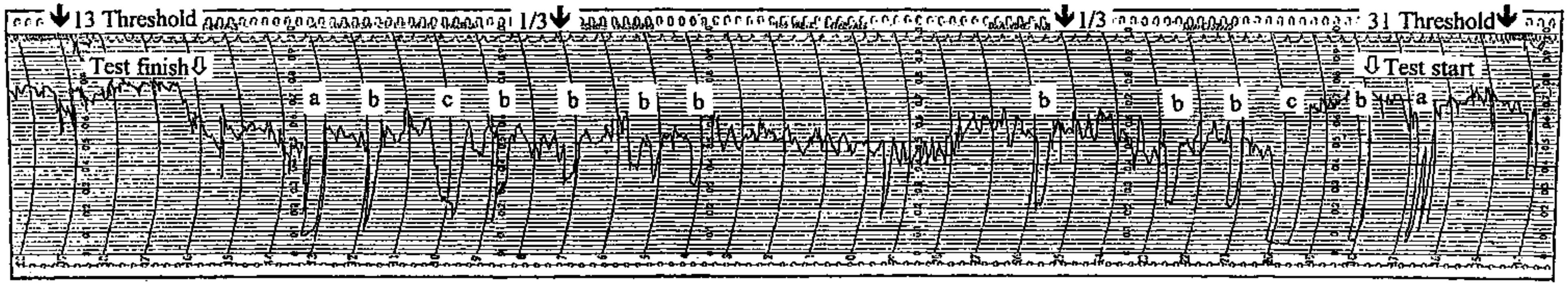

Fig 15 Run 6   10m W of c/l   Vehicle speed 96km/h

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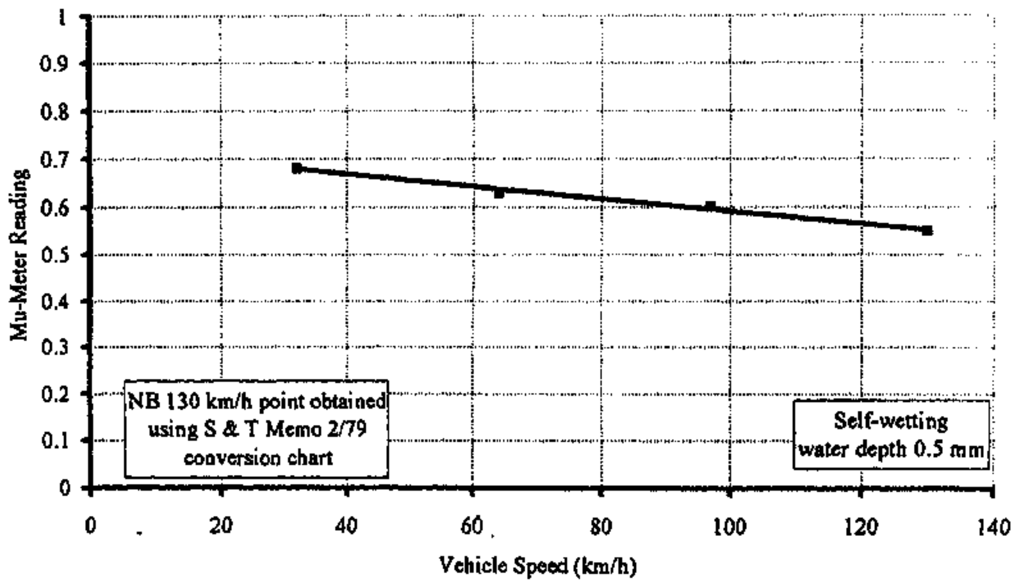
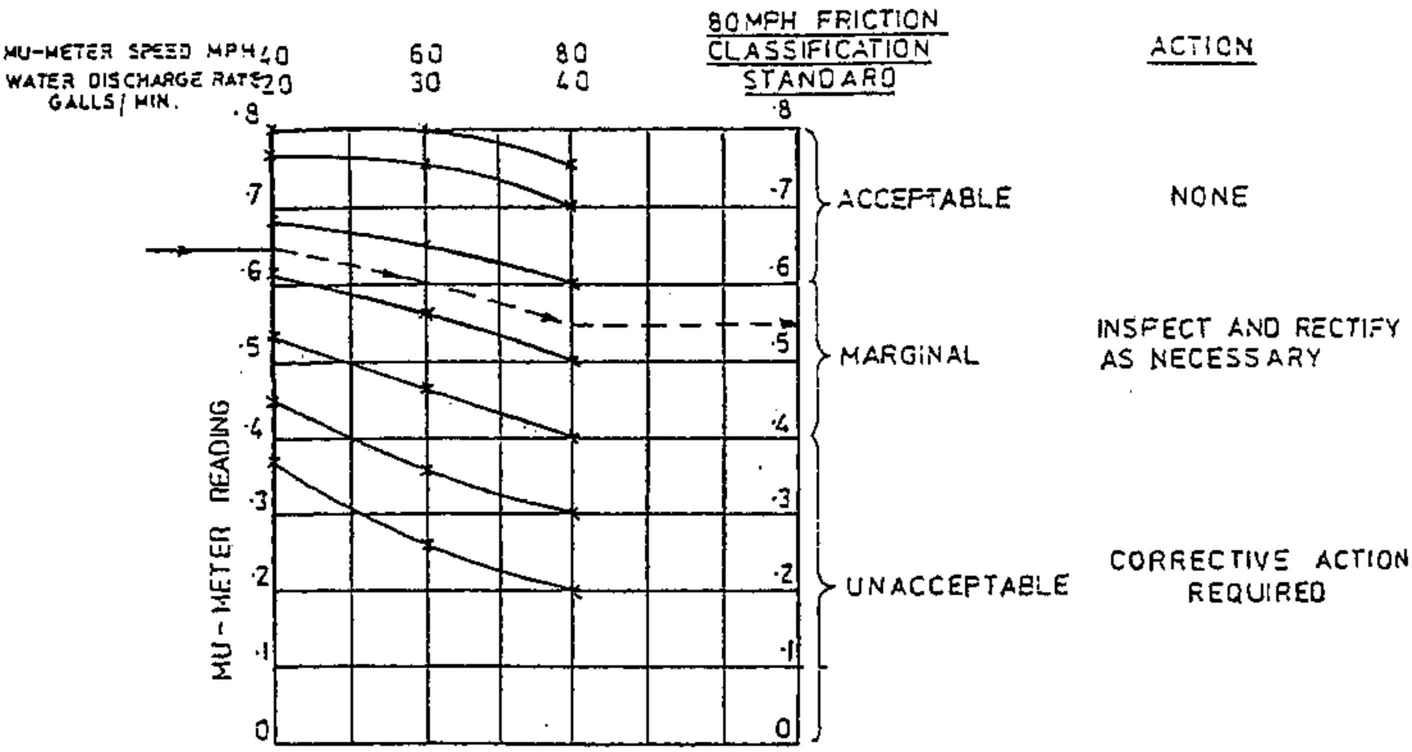


Fig 16 Speed/Friction Curve Hong Kong Kai Tak Airport Runway 13/31

Attachment

Relationship between Mu-Meter readings at different speeds under self-wetting conditions



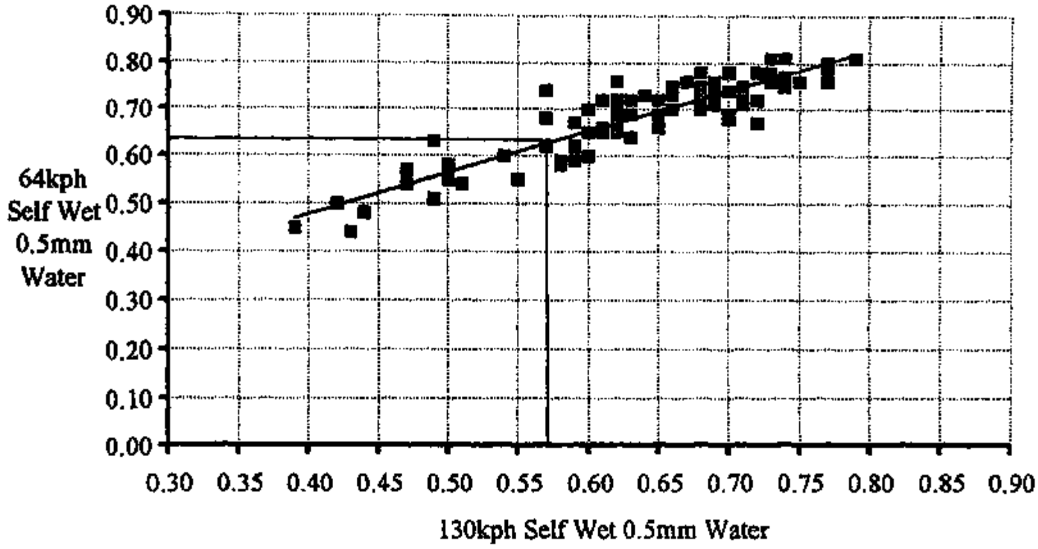
NOTE 1 THE SPEED RELATIONSHIP IS TAKEN FROM S & T MEMO 2/79

NOTE 2 THE CLASSIFICATION STANDARD AND ACTION IS FROM STANAG 3811

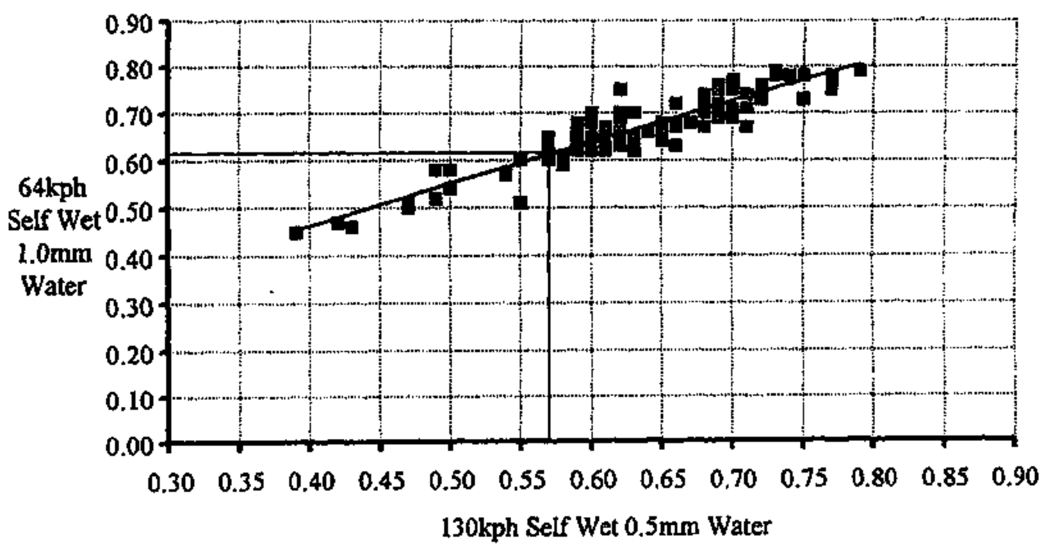
RELATIONSHIP BETWEEN MU-METER READINGS AT DIFFERENT SPEEDS UNDER SELF-WETTING CONDITIONS

EXAMPLE — A READING OF ·65 AT 40 MPH USING A WATER DISCHARGE RATE OF 20 GAL/MIN IS THE EGUIVALANT OF ·55 AT 80 MPH USING A DISCHARGE RATE OF 40/GALL MIN AND GIVES A FRICTION CLASSIFICATION STANDARD OF 'MARGINAL'

FIG. 8



a) Comparison of 130km/h (80mph) and 64km/h (40mph) results at 0.5mm water depth



b) Comparison of 130km/h (80mph) at 0.5mm water depth and 64km/h (40mph) results at 1.0mm water depth

APPROACH BRIEFING CARD

APPROACH BRIEFING

(ACCOMPLISHED AT LEAST 5' PRIOR TO DESCENT)

* WEATHER

  DESTINATION AND ALTERNATE AIRPORT

* CHART INDEX AND EFFECTIVE DATE CHECK STAR AND APPROACH CHART

* USE RUNWAY AND TYPE OF APPROACH

* FMC DESCENT PATH REVIEW

* NAV/RAD PAGE REVIEW

  CHECK NAVIDS SET TO MEET STAR AND APPROACH REQUIREMENT

* LANDING DATA

  CHECK LANDING WEIGHT, VREF, TRANSITION ALTITUDE AND QNH PRESET

* APPROACH MINIMUM

  ILS APPROACH -- DH/MDA

  NON-PRECISION APP. -- MDA/MISSED APP POINT

* GO AROUND PROCEDURE

* MISSED APPROACH PROCEDURE

---

* HOLDING TIME AND MIN. DIVERSION FUEL

Report on Human Factors
and
Performance Aspect

Accident to China Airlines Boeing 747-409B (B-165) on 4 November 1993 at Hong Kong International Airport

Psychologist's Comments

These comments are intended to be read in conjunction with the report of the inquiry into this accident. They do not therefore contain any narrative of the events of the accident, but seek to help to clarify certain issues. The author has not been able to interview the pilots concerned, and the following is based on examination of the written evidence available and conversation with the DoT AAIB inspector concerned.

The questions addressed include:

- Why did the captain partially open the thrust levers, rather than engage reverse thrust, immediately after touchdown?
- Why did the first officer fail to tailor the degree of roll demand that he was applying to the aircraft to the aircraft's behaviour?
- Why was the captain unaware that the autobraking was disengaged and not slowing the aircraft?
- Why did the captain reduce the reverse thrust as the end of the runway approached and attempt to take the last turn-off?
- Is there any evidence that the windshear event on approach influenced the crew's subsequent behaviour, and was the auditory warning of windshear ignored?
- Was the working relationship between the crew members appropriate to the safest possible conduct of the flight?

Failure of the captain to select reverse thrust immediately on touchdown

In this accident, as in many others, a number of factors have combined to produce the overall result, but it is probably fair to suggest that had the captain engaged reverse thrust immediately on, or very shortly after, touchdown the series of events that followed would have been avoided. Had the captain selected reverse thrust promptly, he would have been unable to push the thrust levers forwards, the speedbrakes and autobrakes would have operated normally, the roll may well not have occurred, and the aircraft would have stopped in the length of the runway. It may therefore be suggested that this small area of behaviour is important and merits examination in some detail.

The captain's failure to engage the reverse thrust promptly might be interpreted as suggesting that the captain had not appreciated the primary and particular importance, in the landing that he was undertaking in the conditions prevailing, of ensuring that the aircraft was brought to a stop in the available runway length. Further evidence for this supposition comes from the fact that an autobrake setting of only two was selected. This was a routine setting and there had been no discussion or comment on it between the pilots before touchdown. The evidence given by the captain also shows that he did not appear to regard this landing as potentially especially difficult or unusual. He had been to Hong Kong on many previous occasions, and would clearly not have been as anxious about the unusual approach as are many pilots who land there less frequently. He states that the ATIS was announcing visibility of 7 km in rain, and he therefore believed that the rain would not be especially heavy. He also states, when specifically asked 'Can you explain why you did not select reverse thrust soon after touchdown?', that the aircraft changed its attitude very quickly after touchdown before he had time to put in reverse and that his priority was to control roll. When also asked ' When do you select the thrust reversers to the interlock position after landing?', he replied that he did so when the aircraft is stabilised on the ground, and that the most important thing to do in a cross wind is to stabilise the aircraft. It seems clear from these answers that the captain did not regard engaging reverse thrust as the action of first priority after touchdown but as the first action to be taken once he was satisfied that the aircraft was settled on the ground.

These circumstances and answers do not suggest any requirement for an explanation of the events that goes significantly beyond the answers given by the captain. It appears that, after a fairly demanding approach but not one that caused the captain particular concern, he closed the throttles and executed a good landing. It may well be that the conditions in which he found himself on the runway were materially worse than he had anticipated and, as is common in individuals who find themselves in a situation that is worse than they expected, he devoted a large amount of concentration (or, put another way, all of his information processing resources) to what he regarded as the primary aspect of his task - ensuring that the aircraft was settled on the runway before carrying out any other action (engaging reverse thrust). In everyday life - when at a critical point in driving, or even playing a video game - it is easily possible to be asked a question, to hear and understand it, to know what the answer is, yet not wish to answer until the critical period in the primary task has passed, simply because the information processing system is swamped. Under such circumstances, especially when the consequences of error are great, behaviour usually progresses in a deliberate and possibly slower than normal manner rather than in an impetuous, ill-considered way.

A difficulty with the above explanation is that the captain not only failed to select reverse thrust after touchdown, but actually opened the thrust levers for a few seconds after touchdown before closing them just before the aircraft started to roll. Thus, although a simple failure to select reverse thrust may be plausibly explained in terms of the captain's normal behaviour (waiting for the aircraft to be fully settled on the ground before selection) possibly exacerbated by a special deliberatness of behaviour during this particular rather demanding landing, the same cannot be done for the opening of the thrust levers since this is not a form of behaviour that would have any correlate in a normal landing. It is therefore suggested that captain must either have moved the levers open both unconsciously and inadvertently, or have opened them purposefully and consciously. It is difficult to consider any reason why the captain should have done the latter unless he was already unhappy about the landing on touchdown and, in opening the thrust levers, was preparing for the possibility of a go-around, only closing the throttles some four seconds later when he had satisfied himself that the aircraft was solid on the runway (and before the onset of roll). It is even possible that the captain was only *considering* the possibility of a go-around but that his thoughts started to spill over into partial execution of the action that he was contemplating. Were this explanation true, it would not be surprising that, in the heat of events when the throttles had been closed again, the captain would have failed to bring to mind the fact that opening the throttles would have inactivated the autobrakes and spoilers. This explanation may seem implausible, however, since it would seem much more likely that the captain would have experienced least some relief on achieving a safe touchdown and that taking off again would not have been in his mind.

Another explanation of inadvertent throttle opening may be suggested, however. All of us occasionally do things that we do not intend, but we do not usually make completely random actions: we usually intend to do one thing but actually do another. It is therefore tempting to speculate that, in this instance, the captain's intended action immediately after touchdown was to select reverse thrust but that he inadvertently opened the thrust levers instead. Such an explanation is not completely implausible since well-rehearsed behaviours (opening thrust levers, selecting reverse) need only to be *initiated* consciously. They are then executed automatically unless they are monitored consciously or unless the desired result is clearly not produced. In this instance, the captain's attention would have had large demands on it and this would have increased the probabilities both that he would activate an inappropriate item of automatic behaviour or motor programme (opening the thrust) even though he made the correct conscious decision (select reverse) and that he would have failed to appreciate this incorrect action for some seconds.

In either event, it seems likely that once the captain had closed the throttles for the second time, he would have appreciated the condition of the aircraft and selected reverse thrust had his attention not then been taken by the aircraft starting at this point to roll. Had reverse been selected at even this point the aircraft would probably have stopped in the length of the runway even in the absence of the autobrakes. The roll must therefore be regarded as a very important factor in preventing the selection of reverse thrust, and the first officer's behaviour that produced this roll is now considered.

Failure of First Officer to control roll appropriately

Broadly speaking, humans can operate equipment and exercise skills in either 'open loop' or 'closed loop' ways. Normally, people operate analogue controls that produce analogue responses (when steering a car or maintaining the attitude of an aircraft) in a closed loop way. A given amount of control input produces an observed degree of system behaviour and this produces a further tailored degree of control input. Control input and system behaviour are thus closely matched. When operating in open loop mode, however, a certain stimulus produces a fixed control response from the operator regardless of its consequences on the system. The loop may be open because the operator is prevented from observing the system response, because he has never learned to observe it, or because he has for some reason developed a rigid pattern of behaviour that he fails to tailor to the situation.

It would appear that, in this case, at least two of these conditions prevailed. The first officer may not have been giving all of his attention to the control of roll and he had, furthermore, gained a great deal of experience on aircraft types on which full aileron during the landing roll would not have produced sufficient lift differential between the wings to produce significant roll. Thus his experience would have tended to have produced in him a fixed 'open loop' response to crosswind landings that would have comprised applying a considerable amount of aileron with no requirement for monitoring its effects. Applying this behaviour during the landing in question on this swept wing aircraft, however, clearly produced an unacceptable aircraft response. It is interesting to note that even though the first officer appears to have been operating in 'open loop' mode, one might have expected that the roll produced in the aircraft, in the same direction as the aileron demand, would have caused the first officer to realise what was happening and serve as a stimulus for him to operate in a closed loop manner, tailoring aileron demand to the effect produced. Put another way, it is surprising that, when the aircraft started to roll, the first officer did not appreciate that it was his action that was causing it to do so. Not only did the first officer not appear to perceive this, but he also failed to change his behaviour when the captain called 'Wait, don't roll too much' and, three or so seconds later, 'Don't roll too much', or even when the captain intervened on the control wheel.

Although the first officer appears, probably largely because of his experience, to have been operating 'open loop', the captain has plainly been operating in a closed loop way and appreciated the aircraft's roll, appreciated the reason for it, corrected it, and then corrected it again. This problem, arriving within five or six seconds of touchdown, would clearly have been sufficient to have prevented the captain from selecting reverse thrust at this time. This is because the captain, unlike the first officer, was clearly engaged in controlling the aircraft's roll in a closed loop way. He observed the roll, called to the first officer, and intervened on the control wheel, and these events would almost certainly have demanded sufficient of his processing resources to prevent him from undertaking any other activity. It was a further three or four seconds before the first officer called 'Autobrakes we no have', and the following section addresses this issue.

Failure by crew to perceive the absence of autobrakes

It was not until some 15 seconds after touchdown that the first officer noted the absence of autobraking. This may seem a long period of time to have elapsed without the aircraft slowing and without the crew appreciating it. It is likely, however, that the events already described above were directly responsible for preventing the crew from having sufficient spare capacity to monitor the state of the autobrake system or from realising from direct observation that the aircraft was not slowing.

This failure of the crew to appreciate the absence of an automatic system that they believed was selected and that should have been operating is a particular example of the problem sometimes referred to as 'mode awareness' of automatic systems. It is very easy for crews in aircraft in which many functions can be undertaken manually or in a variety of automatic modes to be unaware, for a variety of reasons, of the precise state at any given time of these modes of operation. If the crew members believe that they have set the aircraft up in a particular way, then they may well continue to believe or to assume that the aircraft is behaving in the way they intended. This factor can be exacerbated by a related phenomenon known as 'overtrust'. Since many automatic systems in modern aircraft are complex, preventing the pilot from having a detailed knowledge of the ways in which they function, the pilots have little alternative than to assume that things are working correctly, especially since they normally do. In this accident, the fact that the pilot selected his habitual setting (of two) for the autobrake system suggests, albeit weakly, that he regarded this system as something that could look after itself with only the minimum of intervention from himself.

There are, of course, many advantages to automation but, because of problems such as those outlined above, the degree of automation being introduced in modern aircraft is now being widely questioned (eg NASA studies on 'Human Centered Automation'). In this particular accident, it is therefore worth questioning whether the presence of an autobrake system on the aircraft was beneficial or detrimental. It could be argued that, in any circumstance, the presence of an autobrake system must be helpful since it offloads a pilot task and the pilot, if unhappy, can always over-ride it simply by applying the brakes in the normal way. It must therefore confer a benefit in terms of reducing pilot workload and, what is more, do so without conferring any penalty.

It might alternatively be argued that the absence of an autobrake system does not generate any particular difficulty, since operating the brakes is, for all experienced pilots, a well rehearsed and automatic skill that does not add significantly to overall pilot workload during the landing roll. Exercising this skill does, however, serve to keep the pilot ' in the loop' with regard to the overall control of the aircraft (especially with regard to its speed) during touchdown and the braking roll. The essential difference, therefore, between automatic and non-automatic braking systems is that non-automatic systems inevitably keep the pilot 'in the loop', but that automatic systems require monitoring to ensure their correct operation. It probably is, perhaps paradoxically, less demanding for a busy pilot to exercise a well established skill than it is intermittently to monitor the operation of an automatic system. It is tempting to suggest that if the pilot needs to give his attention to a system, there should be some form of warning or attention getter to facilitate this, and that in this case the absence of autobrake should have been more clearly annunciated to this busy crew. Whereas such logic may be appropriate to certain clear cut failures, this cannot be said for the absence of autobrakes (since they may have been deselected for good reason, eg the aircraft may have been going around from the touchdown), and careful thought would need to be given to the design of a warning that would be appropriate to the degree of significance that autobrake absence has on the crew.

Overall, however, it is reasonable to suppose that had this aircraft not been fitted with autobrakes, it is unlikely that this accident would have occurred.

It should finally be noted that it is plainly undesirable to keep the pilot 'in the loop' during normal flight when to do so would be extremely tedious. The difference during the landing roll is that it is of short duration and is a time when it is critical for the pilot to be in good contact with all aspects of the aircraft's behaviour. Since much has recently been written about the requirement for the automation that is being introduced on flight decks to be 'human centred' rather than only technology driven, some consideration (in the light of this accident) of the overall desirability and usage of autobrake systems may be appropriate.

Captain's reduction of reverse thrust and attempt to turn off the runway

It is probable that the late engagement of reverse thrust and the absence of autobrakes would have prevented this aircraft from stopping on the runway whatever the crew's behaviour subsequent to about 15 seconds after touchdown. It is nevertheless interesting that, although the aircraft was still travelling at about 70 kts some seven seconds before the end of the runway was reached, the captain reduced the reverse thrust such that all thrust reversers were stowed some three seconds before the end of the runway when the aircraft was still travelling in excess of 40 kts.

Two possibilities present themselves with regard to understanding this behaviour. The first is that the captain, under a good deal of stress, reverted to well established patterns of behaviour and controlled the aircraft in the way that he normally would when approaching the turn off that he intended to take, and did so on this occasion without any regard for the speed of the aircraft. This explanation may also hold for the attempt to turn onto the taxiway when the captain applied rudder to the aircraft while it was still travelling at almost 50 kts. This explanation suggests that the captain may have paid no regard to the speed of the aircraft. It is also possible, however, that he was aware that the aircraft was still fast for its position on the runway, but reduced the reverse thrust because he normally did so at about 70 kts. He then did so as a matter of habit on this occasion even though the external observer might have expected him to demand all of the stopping power that was available to him in the extreme circumstances with which he was presented.

The second possible explanation (not necessarily independent of the first) is that he misperceived the speed of the aircraft and believed it to be travelling more slowly than it actually was. Thus he may have believed that he was actually travelling sufficiently slowly to have no requirement for the reverse thrust and to be able to turn the aircraft safely. There are two reasons for giving some credence to this possibility. The first is that it is notoriously difficult, even for those with some experience, to judge the speed of the 747 given the height of the pilot from the ground. The second is that our judgement of speed is to some extent relative rather than absolute, so that if we have just been travelling quickly and then rapidly decelerated, we may well feel ourselves to be travelling more slowly than we actually are. To some extent, this was the situation in which this captain found himself, and I therefore believe that it is possible he may have believed himself to have been travelling sufficiently slowly at the end of the runway for his actions to be appropriate.

Probably more likely, however, is some combination of the above effects. A stressed captain seeing the end of the runway approaching (possibly never before having had to make a judgement in the 747 about exactly how quickly he was going and whether he would be able to stop the aircraft in a given distance), with a relatively poor view of the end of the runway through the rain and wet windshield, failed to perceive that his behaviour was not appropriate and controlled the aircraft in his habitual manner, probably hoping that the situation would resolve itself.

Windshear and the subsequent behaviour of the crew

During the approach, the aircraft experienced a windshear that was sufficient to activate the aircraft's amber windshear warning (noticed by the captain), that produced an aural 'WINDSHEAR' warning, and produced the red legend 'WINDSHEAR' on the PFDs (noticed by both pilots). In addition, the captain must have noticed the effects of the windshear on the aircraft's speed and altitude. The question is whether this event played any part in the crew's subsequent behaviour.

There can be little doubt that this event would have been fairly stressful to many crews. Flying the approach into Hong Kong is demanding for them in any case, and losing airspeed and altitude when already low and in a built up area with a demanding turn onto finals ahead would be very stretching indeed. This may not have been so for this captain, however. He was already slightly fast on the approach, and the airspeed loss would actually have assisted his approach. He did not respond to the windshear with any dramatic control demand (eg for power), and he executed the remainder of the flight to touchdown entirely appropriately. Nevertheless, it could be argued that this crew effectively ignored the windshear warnings even though the captain was certainly aware of the first as his remark 'Windshear' can be heard on the cockpit voice recorder. The windshear voice warning, however, immediately followed, and was in turn shortly followed by, a GPWS 'Glideslope' voice warning. Embedded in this way it is possible that it may have gone unattended - the captain having given just enough attention to the digital voice to register 'Glideslope' and then transferring his attention back to the principal flying task. Furthermore, the captain had been warned of possible windshear on finals, and would have known of and probably experienced the slightly spurious windshear effect that occurs at Hong Kong as the aircraft turns to the right and, as it were, through the wind on leaving the approach heading as it lines up with the runway. Since, for these reasons, the captain would have been expecting some windshear effects as a relatively normal consequence of this approach, his lack of action may be regarded as not unreasonable, and his handling of the aircraft (as noted above) did produce a good touchdown.

Since I believe that the crew's behaviour after touchdown can be explained in terms of the events that occurred after touchdown, I do not believe that it is necessary to suggest that there was a material effect of the windshear on the crew's behaviour during this accident, although such effects plainly cannot be ruled out.

Crew relationship and flight safety

On any flight deck it is the duty of the crew members to try to relate to one another in ways that maximise the likelihood that all of the crews views and ideas will be aired and the best of these acted upon. It is sometimes observed that the well known relative accident freedom that exists in Australian operators may in part stem from the relative lack of subservience to authority shown by Australians and that, conversely, too much respect for authority may be inhibitory of frank flight deck exchanges and therefore not the best way of behaving in the interests of safety.

There is really too little evidence in this accident to make any conclusive comment about this particular crew. It is relevant to note, however, that there was relatively little interaction between the crew members other than that strictly required for the actions of operating the aircraft, and that there was, for example, no discussion of the appropriate degree of autobraking to be set. It is also apparent that the captain yawns several times during the approach. It is possible that he was simply tired, but yawning may also be interpreted as a type of body language that conveys the idea that the activity in hand was something that the captain could manage easily, simply not requiring the intervention or assistance of the first officer. The answers of the first officer to some of the questions that he was asked after the accident suggest that there was a large gap on this flight deck, possibly rather larger than might be desirable, between the statuses of the two crew members, and consequently in their capacity to work as effective members of a team to which they could each make full contributions. This situation may also have been exacerbated by the differences in experience levels and qualification. Each of the crew members had undertaken cockpit or crew resource management training but it should not, of course, be expected that such training can immediately change ways of behaving that may be well entrenched in individuals and even built into the broader culture from which the crew members are drawn. There is a good deal of research presently aimed at providing a better understanding of the effects of national cultural stereotypical behaviour on the flight deck team, and this accident perhaps serves to reinforce the requirement for understanding this difficult and sensitive area.

There is a final observation that may be worth making. It can be argued that the single most important factor that has made aviation as safe as it is currently, has been the extensive introduction and use of procedures for all aspects of aircraft operations, and especially for the flight deck task. The importance of procedures is to relieve the pilot of all thinking and problem solving for events that can be anticipated. The best way of tackling situations and problems is obviously not best identified when they actually arise, but well beforehand when the appropriate responses or behaviours can be decided upon and rehearsed. Thus the more detailed and well thought out flight deck procedures are, and the more specific they are to the nature of the operation, the safer the system is likely to be. The relative absence of detailed specific procedures within China Airlines may thus be a matter that would repay detailed consideration in the light of this accident.

All of the above is speculative, however, and since it may well be unfair it should not be used in any way to judge this particular crew. Since, however, there may be some truth in these ideas, it would seem worth bearing them in mind when the adequacy of crew interaction training in this and other airlines is considered.

Conclusions

It has been suggested above:

- that there is no need to suppose that the windshear event on the approach had a material bearing on the crew's subsequent behaviour
- that the captain had failed, to some degree, to appreciate the difficulty of the landing that lay ahead of him because of the ATIS information and his familiarity with Hong Kong
- that the captain probably did not habitually select reverse thrust promptly after touch down and that his especially late selection on this occasion was caused by the aircraft's roll
- that the first officer was operating in inappropriate 'open loop' manner in applying aileron to counter cross wind, probably because of an inappropriate habit pattern
- that the use of autobrake (and its inadvertent deselection) on this occasion enabled the crew to remain unaware, at a critical time, that the aircraft was not slowing
- that the captain probably failed properly to perceive his speed as the end of the runway approached and behaved in a stereotyped way that was inappropriate to the circumstances

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