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8/92

FOREWORD

General

1. The purpose of the Aircraft Accident Digest is to disseminate accident report information to Contracting States. Publication of the Digest began in 1951. Over the years States have reiterated their interest in the Digest not only as a valuable source of information for accident prevention, but also as a training aid for investigators and educational material for technical schools.

Selection of accidents

2. The Digest contains accident reports selected by the Secretariat from those sent by States. Reports were selected on the basis of:

a) their contribution to accident prevention; or

b) the successful employment of useful or effective investigative techniques; and

c) compliance with Annex 13 provisions including the format of the Final Report.

The Digest should not be seen as being statistically representative of the world distribution of accidents.

Editorial practices

3. The Final Reports are usually published as received. Accordingly, some deviations from standard ICAO editorial practices may occur. Lengthy reports may be abbreviated by omitting redundant information, appendices, attachments or diagrams. Minor changes in presentation and terminology may be introduced to ensure compliance with Annex 13 provisions.

States' co-operation

4. States are encouraged to send to ICAO those Final Reports which meet the criteria of 6.14 in Annex 13. The reports must be submitted in one of the working languages of ICAO, and in the format presented in the Appendix to Annex 13.

Digest publication

5. The Digest is produced once each year and includes accidents and incidents which occurred during a one-year period.

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No. 1

Boeing 727-256, EC-DDU, accident near Bilbao, Spain, on 19 February 1985. Report released by Dirección General de Aviación Civil and Comisión de Accidentes, Spain

SYNOPSIS

IBERIA Boeing 727-256, registration EC-DDU, operating scheduled flight IB-610 (Madrid - Bilbao) collided with a metal structure, a television antenna mast, located on Mount Oiz (1 027 m). The Boeing 727 had taken off from Madrid/Barajas Airport at 0747:00[1] with an estimated time of arrival at Bilbao (Sondica) Airport of 0835:00. The last contact between the aircraft and the Bilbao Airport control tower was at 08.22:07 and it was 40 minutes before they had confirmation of the accident. From an examination of the wreckage and its pattern of distribution on the ground, it can be deduced that the left wing and the bottom of the fuselage collided with the antenna after which the aircraft struck the ground. All on board, 141 passengers and the crew of 7, died in the accident.

Meteorological conditions at Bilbao Airport at 0800 were as follows:

Wind:	Calm
Visibility:	*4 km with mist*
1/8 cumulus:	at 3 000 feet
2/8 stratocumulus:	at 5 000 feet
2/8 altocumulus:	at 10 000 feet
QNH:	1 025
Temperature and dew point:	07°/07°

1. FACTUAL INFORMATION

1.1 History of the Flight

Iberia Boeing B727-256, EC-DDU "Alhambra de Granada" on scheduled flight IB-610 (Madrid - Bilbao) took off from Madrid/Barajas Airport at 0747 with a scheduled arrival time at Bilbao (Sondica) Airport of 0835.

At 0809:58 Madrid Control provided the aircraft estimates and data to the Bilbao tower.

At 0816:03 the first communication was established between IB-610 and the Bilbao tower:

IB-610: "BILBAO TOWER GOOD MORNING, SIX ONE ZERO".

TWR: "IBERIA SIX ONE ZERO, GOOD MORNING, OVER".

IB-610: "WE ARE LEAVING ONE THREE FOR LEVEL ONE HUNDRED TWENTY EIGHT OUT".

---

1. Except where otherwise indicated, all times in this report are in UTC.

TWR: ROGER IBERIA SIX ONE ZERO, STAND BY PLEASE".

At 0816:33, TWR transmitted: "IBERIA SIX ONE ZERO, YOU CAN CONTINUE DESCENT FOR ILS APPROACH TO BILBAO RUNWAY THREE ZERO, WIND IS ONE HUNDRED DEGREES THREE KNOTS, QNH ONE ZERO TWO FIVE AND TRANSITION LEVEL SEVEN ZERO".

At 0816:44 IB-610 replied: "THANK YOU, DESCENDING TO SECTOR MINIMA, ON ONE THOUSAND TWENTY FIVE.

At 0816:48 TWR replied: "CORRECT ONE THOUSAND TWENTY FIVE AND IF YOU WISH YOU MAY PROCEED DIRECTLY TO THE FIX".

At 0816:55 IB-610 replied: "WE ARE GOING TO MAKE THE ... STANDARD MANOEUVRE".

At 0816:57 TWR acknowledged receipt: "ROGER, NOTIFY PASSING VOR".

At 0822:04 the aircraft informed TWR: "SEVEN THOUSAND FEET OVER VOR, IBERIA SIX ONE ZERO STARTING MANOEUVRE"

At 0822:07 TWR acknowledged receipt: "ROGER SIX ONE ZERO". That was the last communication with IB-610.

1.2 Injuries to Persons

Injuries	Crew	Passengers	Others
Fatal	7	141	-
Serious	-	-	-
Minor/None	-	-	-

1.3 Damage to the Aircraft

The first impact with the antenna tore off part of the tyre on the left wheel, the left nose gear door and the left main gear. The left wing was detached completely. Subsequently, following further impacts in the area of the North East slope of Mount Oiz which is covered with pine trees, the entire aircraft was destroyed.

1.4 Other Damage

The metal structure of the "EUSKAL TELEBISTA" antenna with which the aircraft collided and several pine trees were either damaged or destroyed by the impact. The damaged area covered about 20 000 m^2 on the North East slope of Mount Oiz.

1.5 Personnel Information

1.5.1 Captain

Sex:	Male
Age:	51
Licence:	ATPL No 715
License issued:	19-04-1966
Validity:	07-08-1985
Last medical examination:	21-01-1985
B-727 Rating:	16-04-1976

Flying experience (hours)

Total:	13 678
Total on type as co-pilot:	211
Total on type as captain:	4 671
Total previous six months:	29
Total previous 90 days:	29
Total previous 30 days:	17
Rest time prior to flight:	72 hours

Note.— From 19 June to 24 July 1984, there was a strike by pilots within the airline. Because of this, on 18 July the Captain's contract was cancelled. On 19 November 1984 he rejoined the airline. From that date until 29 November 1984 he followed the appropriate training course and took and passed the relevant flight checks.

1.5.2 Co-pilot

Sex:	Male
Age:	38
Licence:	ATPL No 1 815
Licence issued:	16-01-1980
Licence validity:	17-04-1985
Last medical examination:	20-03-1984
B-727 rating:	04-05-1981

Flying experience (hours)

Total:	5 548
Total hours on type:	2 045
Total previous six months:	283
Total previous 90 days:	143
Total previous 30 days:	52
Rest time prior to flight:	24 hours

1.5.3 Flight Engineer

Sex:	Male
Age:	38
Licence:	Flight engineer No. 682
Licence issued:	21-03-1972
Licence validity:	05-03-1985

Last medical examination:	23-02-1984
B-727 rating:	30-06-1980

Flying experience (hours)

Total:	2 721
Total on type:	2 721
Total previous six months:	288
Total previous 90 days:	117
Total previous 30 days:	50
Rest time prior to flight:	48 hours

1.5.4 Cabin Crew

All members of the cabin crew were in possession of the relevant certificates and had carried out their training courses.

1.6 Aircraft Information

Model:	B-727-256
Manufacturer:	The Boeing Company
Date of Manufacture:	1979
Serial No.:	21,777
Registration:	EC-DDU
Owner:	IBERIA, Líneas Aéreas de España

Airworthiness certificate:	No. 1 971
Date of last renewal:	13-05-1984
Validity:	13-05-1985

Maintenance Record

Aircraft total hours:	13 408
Total cycles:	12 347

	Hours	Date
Total since check A:	115	29-01-85
Total since check B:	471	12-12-84
Total since check C:	928	28-08-84

Engines: Pratt & Whitney JT8D-9A

Time since overhaul				Total time
Position	Serial no.	Hours/cycles	Date	Hours
1	665 963	5 094:44/4 475	15-11-82	20 685:44
2	665 795	1 905:37/1 629	04-04-84	23 487:37
3	665 809	775:52/663	21-09-84	22 909:00

Mass and centre of gravity

Maximum authorized take-off mass:	83 552 kg
Actual take-off mass:	66 109 kg
Centre of gravity at the time of the accident:	25.00% MAC within limits

1.7 Meteorological Information

METARs at Bilbao Airport were as follows:

0730

Wind	110/04
Visibility	4 000 m
Conditions	mist
Clouds	2/8 cu at 2 500 ft 4/8 sc at 4 000 ft
Temperature & dew point	07°/07°
QNH	1 025
No significant changes forecast	

0800

Wind	110/04
Visibility	4 000 m
Conditions	mist
Clouds	1/8 cu at 3 000 ft 2/8 sc at 5 000 ft 2/8 ac at 10 000 ft
Temperature & dew point	07°/07°
QNH	1025
No significant changes forecast	

0830

Wind	110/04
Visibility	4 000 m
Conditions	mist
Clouds	2/8 sc at 4 000 ft 4/8 ac at 8 000 ft
Temperature & dew point	07°/07°
QNH	1 026
No significant changes forecast	

On 17 and 18 February, a light surface storm crossed the Peninsula eastward with a system of associated fronts. It moved along parallel 40°N carrying considerable cloud particularly over the Northern half of Spain. On 19 February there were still traces of the clouds from this storm over the Peninsula. Between the Gulf of Cadiz and the North of Morocco there was a low pressure system giving rise to clouds over Andalucia. Over Europe there was a powerful anticyclone of 1 041 mb producing a wind from the first quadrant at all levels towards the Cantabrian Mountain Range, generating stationary clouds over the coast.

The 0900 Meteosat photograph confirms low clouds over the whole of the Basque Country, although they did not form a continuous layer.

According to the Bilbao Airport METAR, between 0600 and 1100 the sky was almost covered with low fragmented clouds, the bases of which were at two distinct heights, 2 500 and 4 000 feet. The prevailing mist, high humidity generated overnight and the proximity to the Cantabrian Sea, created a visibility which varied from four to five kilometers.

Although, according to ICAO Annex 3, METAR data relate only to the airport and its immediate vicinity, taking the meteorological conditions into account, it can be assumed that cloud conditions would be very similar over a greater area, possibly over the whole East Cantabrian coast region.

Because of the European anticyclone affecting the North of the peninsula, clouds were stratified so that the cumulus and stratocumulus clouds were between 1 500 and 3 000 feet thick.

Surface wind at the airport varied between 050° and 110° at a speed of three to five knots, so that reduced visibility persisted for several hours because of the wind speed which was lower than might have been expected given the prevailing meteorological conditions, possibly because of the effects of the local orography in the vicinity of Bilbao Airport.

1.8. Aids to Navigation

VOR/DME

IDENT:	BLV
EM:	A9W/PON
Transmitting on:	115.9 MHz
Coordinates:	43°18'15"N 02°56'01"W
Operating hours:	24
Location:	0.30NM on a magnetic heading of 294° from the airport reference point.
Power:	0.2 kW
DME:	Channel 106X

NDB

IDENT:	BLO
EM:	NON/A2A
Transmitting on:	370 KHz
Coordinates:	43°19'26"N 02°19'26"W
Operating hours:	24
Location:	2.43NM on a magnetic heading of 309° from the airport reference point.
Power:	0.25 kW
Range:	70 NM

NDB

IDENT:	BIL

EM:	NON/A2A
Transmitting on:	323 kHz
Coordinates:	43°11'17"N 02°35'47"W
Operating hours:	24
Location:	27 070 m from threshold of Runway 30 and 150 m to the right of the extended runway centre line in ILS approach direction.
Range:	50 NM.

L

IDENT:	B
EM:	NON/A2A
Transmitting on:	395 kHz
Coordinates:	43°22'26"N 03°02'01"W
Operating hours:	Airport timetable
Location:	7.04 NM on a magnetic heading of 320° from the airport reference point.
Power:	0.02 kW
Range:	15 NM

1.9 Communications

The Bilbao Airport Tower is equipped with ground-air communications equipment with the following characteristics:

Approach — APP

Service:	APP
Call sign:	Bilbao APCH
EM:	A3E
Transmits & receives on:	120.7 MHz
Operating hours:	OCT/MAR 0630/2100

Tower — TWR

Service:	TWR
Call sign:	Bilbao
EM:	A3E
Transmits & receives on:	118.5 MHz 121.7 MHz (taxiing) 121.5 MHz (emergency)
Operating hours:	OCT/MAR 0630/2100

Each piece of equipment transmits and receives on a single frequency and incorporates a recorder on which all communications were recorded.

1.10 Aerodrome Information

Not relevant.

1.11 Flight Recorders

The aircraft was equipped with a CVR (Cockpit Voice Recorder) and a FDR (Flight Data Recorder). Both were installed behind the pressure bulkhead in the tail cone and were recovered on the day of the accident.

1.11.1 CVR

The CVR was a Sundstrand AV-557C, Serial no. 9060, P/N 980-6005-074, Date Code 1.078. When dismantled, it showed evidence of slight damage to the casing although the tape was in good condition for listening.

1.11.2 FDR

The Flight Data Recorder was a Sundstrand FA-542, Serial No. 2724, P/N-101035-1. When removed it was found to be in good condition for analysis. It recorded the following parameters:

— Time
— Heading
— Radio transmission keying
— Indicated airspeed
— Altitude
— Normal acceleration

1.12 Wreckage and Impact Information

The first impact occurred at 43°13'43"N-02°35'26"W at around 30 km SE of Bilbao Airport. It was a collision with the 54 m high antenna mast, the base of which was close to the top of Mount Oiz at a height of 1000 m.

The first impact occurred approximately 10 seconds after starting the turn towards the final approach to Runway 30 at Bilbao Airport. At that time the aircraft was under control with a bank of 29°, a rate of descent of 600 ft/min and an IAS of 208 knots. The engines were at low power and the controls on automatic.

The initial collision with the platform, which was 42 m from the base of the antenna mast, started with the bottom left part of the nose in front of the front gear housing. It continued to graze the lower left part of the fuselage and when the left wing collided with it, the wing was torn off.

The left wheel, the door of the nose gear and other parts of the door operating mechanism were separated on impact with the platform mentioned above, close to the mast at a distance which was consistent with the impact. Some parts of the aircraft from the nose to the wing mesh, the air conditioning system and part of the thermal insulation separated on impact. In addition, the main gear and the support beam were found, scattered in a consistent pattern (the closer to the point of impact, the lower the weight/area ratio). In addition, the detached wing turned over and hit some rocks close to the peak. Its movements followed the slope of the hillside showing the trajectory of the aircraft and it ended up 620 m from the mast.

After losing its left wing and out of control, the aircraft followed its path at the moment of impact. It continued along a parabolic trajectory in the vertical plane and turned anti-clockwise around its longitudinal axis, hitting the mountainside upside down at 930 m from the antenna mast. It continued, razing the forest, and opened up a path in which it strewed remnants of the tail, the upper-front fuselage and part of engine number 1. The main wreckage (nose gear with right wheel, right main gear and the whole of engines 2 and 3 as well as the rear part of the fuselage including the stairs, the location of which was easily identified from the shape) were left in a stream bed at the edge of the hillside.

1.13 Medical and Pathological Information

Because of the nature of the impact of the aircraft with the ground following the collision with the antenna, there were no survivors of this accident.

All victims showed mutilation and/or polytraumatism as the cause of death. There is no evidence of deaths caused by asphyxiation or fire.

1.14 Fire

There was no generalized aircraft fire as a result of the impact but there were some small isolated fires caused by fuel spillages from the broken tanks and from contact with metal wreckage heated by the energy generated from the impact. The parts most affected were the tail cone and the engines.

1.15 Rescue and Survival

About 40 minutes after the last communication between the aircraft and Bilbao Tower, providing information about the aircraft's passing over the VOR, confirmation of the accident was given by telephone. The local medical and firefighting services set off immediately for the site of the accident. At the same time the local security forces cordoned off the accident area in order to protect the wreckage and safeguard the rescue work. Rescue of the reamains of the aircraft's occupants was complicated and was coordinated in two stages. The first went as far as the lower slopes of the mountain. From there helicopters operated to premises set up specifically for the purpose of identification in the city of Bilbao. There was no possibility of survivors in this accident.

1.16 Tests and Research

1.16.1 Automatic Flight Control System (AFCS)

A Sperry SP-150 MBV was installed on the aircraft.

The "Automatic Pilot" (A/P) offers in-flight control on the three axes of the aircraft and permits Category I and Category II approaches.

Its controls were located on the rear electronic panel of the centre pedestal, within reach of both pilots. It comprised the following elements (Figure 1):

— the "PITCH SELECTOR" control which permits selection of the following modes:

VERTICAL SPEED, the position to which it is returned by spring whenever any other mode is cancelled;
PITCH HOLD (holds the angle of attack);
PDC SPEED (speed programmed by the PDC or by the pilot);
IAS HOLD and MACH HOLD (these positions were not activated in this system).

— the "VERTICAL SPEED" control which allows the pilot to send to the A/P a specified rate of climb or descent or to maintain altitude. If this control is operated, the Pitch Selector switches to the Vertical Speed position whatever mode has been selected.

— the "TURN" control which controls the aircraft bank angle. It can be held in any position and has a preset to the neutral position which is necessary to connect the A/P.

— the "HEADING SELECTOR" switch which allows the A/P to turn the aircraft to the selected heading.

— the "ENGAGED-DISENGAGED" switch which engages the pitch and banking axes simultaneously. It is operated by solenoid when the appropriate electrical circuits close and switches to the "DISENGAGED" position when one of the circuits opens. If any of these circuits is not switched to open by the control on each of the pilots' control columns, the (flashing red) "AUTOPILOT DISENGAGED" warning lights on the panel in front of both pilots light up.

— the "NAV SELECTOR" switch which selects the following modes:

AUX NAV (this position was deactivated on this system)
NAV LOC
TURN KNOB
AUTO G/S
MAN G/S

— the "ALT SEL" switch which is used together with the altitude selector to capture the pre-set altitude. It is a "press-to-make, press-to-break" switch. On the switch itself there are two lights, ARM (amber) and ENG (green).

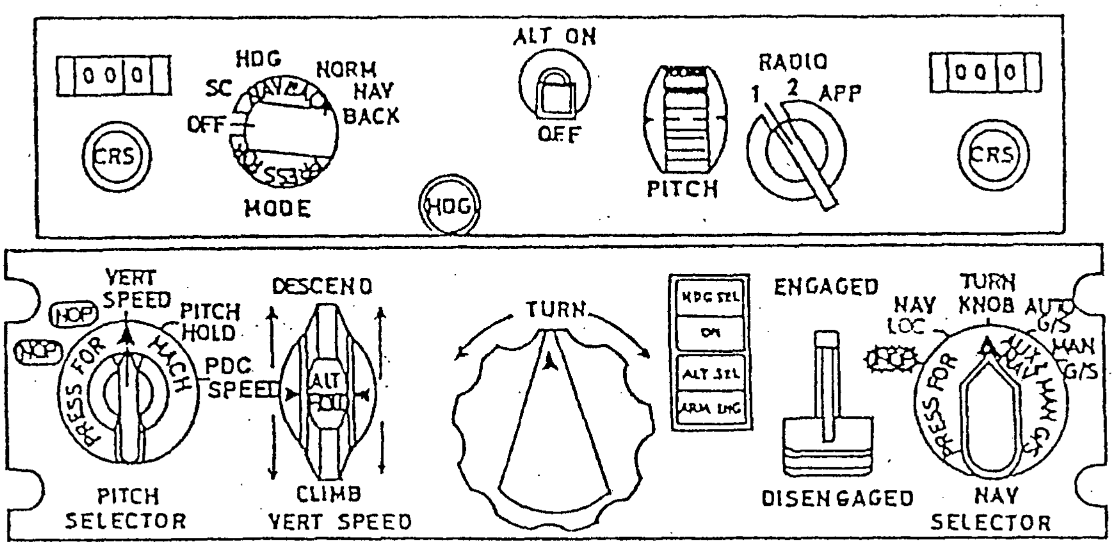


Figure 1

1.16.2 Altitude Alert System

The aircraft had a Sperry system installed (Serial Number 2020312 and P/N 25933564-908 with modification status A,B,D,E,F,G,J,S as indicated on its identification plate.

This system provides visual and audible signals when the aircraft deviates from or approaches a selected altitude. The altitude must be set in advance by one of the pilots.

The altitude alert system comprises the following elements (Figure 2):

— the "ALTITUDE SELECTOR", located on the front electronic panel, accessible to both pilots and comprising:

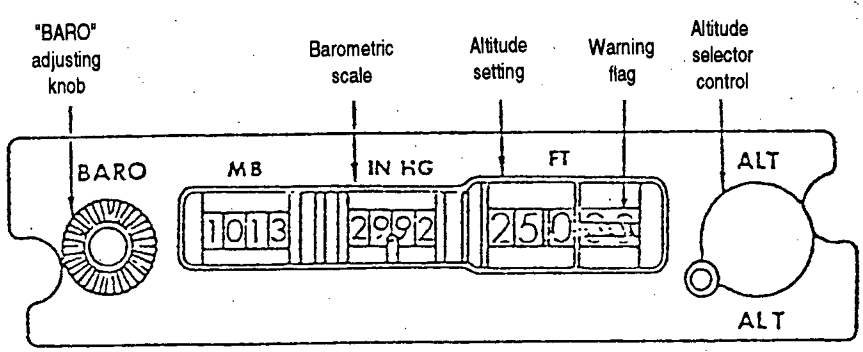
An adjusting knob marked "BARO" with a double window to display the barometric scale in both millibars and inches of mercury;

An altitude selector control with which the pilot can preset the required altitude in increments of 100 ft up to a maximum of 49 000 ft. The setting is displayed in a window in which a warning flag appears (black and white stripes) in case of equipment failure. If altitudes below sea-level are selected a red flag (negative altitude indicator) appears. When pressed, the altitude selector control acts as a "RESET" button switching the approach/ deviation mode to approach mode. One full turn of the selector knob equals a variation of about 3 000 ft on the altitude indicator dial.

— the ACOUSTIC WARNING UNIT, located on the ceiling panel. The audible signal is a musical tone with a duration of one or two seconds.

— TWO LIGHT SIGNALS, one located on each control console which have "ALTITUDE ALERT" inscribed on them.

— the SYSTEM INHIBITION DUE TO FLAP POSITION SWITCH, located in the right gear wheel housing. It switches on when the flap position is greater than 25°.



ALTITUDE SELECTOR

Figure 2

The altitude alert system operates in the following sequence:

When the aircraft is heading toward the altitude selected, at 900 feet from it the audio generator switches in and steady amber signal lights come on. As it continues to approach the altitude selected, at 300 feet from it, the signal lights switch off and the system automatically switches to deviation mode. As long as the difference between the altitude selected and the altitude of the aircraft is less than 300 ft there is no warning signal. If it is more than 300 ft, the audio generator is activated and the warning lights flash. Flashing continues until the aircraft is 900 feet from the altitude selected, at which point the system automatically resets to approach mode.

In general the altitude alert system is used in conjunction with the A/P. In this case, the operating sequence is as follows (Figure 3): once the pilot has selected the required altitude and has set the barometric pressure with the "BARO" control, the altitude selector knob is pressed to "RESET", the system is armed by pressing the "ALT SEL" switch located on the A/P control panel and the amber ARM light incorporated in the switch itself lights up. When the aircraft reaches 900 ft from the altitude selected the audio generator switches on and the steady, amber "ALTITUDE ALERT" lights on the panels in front of each pilot switch on. While the aircraft is still approaching and is 300 ft from the altitude selected, the lights go off and depending on the rate of descent and the altitude error, at a pre-set distance from the altitude selected the amber ARM light goes out and the green ENG light comes on indicating that the aircraft has changed to ENGAGED mode and is starting to level off towards the altitude selected until it captures it, at which point it changes to capture mode. This light remains on until the aircraft leaves the captured altitude.

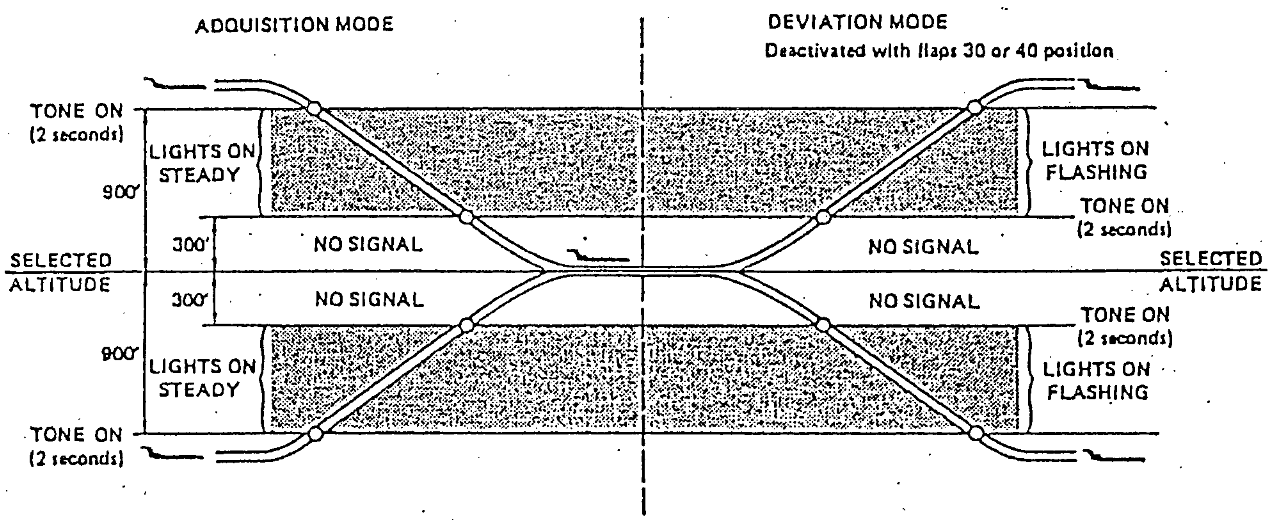


Figure 3

1.16.2.1 Tests

Tests have been conducted on the operation of the altitude alert system:

a) Laboratory tests;
b) Flight tests.

Laboratory tests:

1. The altitude alert equipment was recovered from the aircraft wreckage with substantial impact damage. In the altitude selection window the ten thousand drum showed no digits (indicating a selection of less than 10 000 feet). On the thousands drum the figure 4 was displayed and the hundreds drum showed the figure 3.

The barometric pressure selection window only showed inches of mercury (with a display of 30.27 equal to 1 025 millibars). The millibar window was missing.

It was discovered that the ten thousands and thousands drums were stuck and did not rotate about their axes. It could be seen that, as a result of the impacts, the upper cover of the device had become separated and folded outwards, revealing on the inside the mark left by a cog wheel from the altitude selector mechanical transmission system. This led to the assumption that there was a first impact which blocked the spindles of the wheels that rotate the drums.

On the hundreds drum there was slight play from number three to number two (this movement did not rotate the mechanical transmission). The single digit drums of the pressure indicator window showing inches of mercury could be moved.

In view of all this, the possibility was considered of examining it in the laboratory to see whether the positions of the mechanical parts of the system or its electronic components would make it possible to determine the last altitude selection.

Once it had been analysed, it was found that no conclusions other than those indicated previously could be drawn, primarily because the fine synchro was missing from the electronic components, having been lost in the accident; the coarse synchro was found to be off its locking position with its rotor spindle rotating freely and the mechanical component does not have an initial reference position.

2. In order to analyse the performance of the system, a device similar to the one recovered from the accident (SPERRY P/N 2593564-908, S/N 3120447 with a similar modification status) was used. Two types of test were carried out, one study operating it as an independent device and the other as a system connected to the A/P.

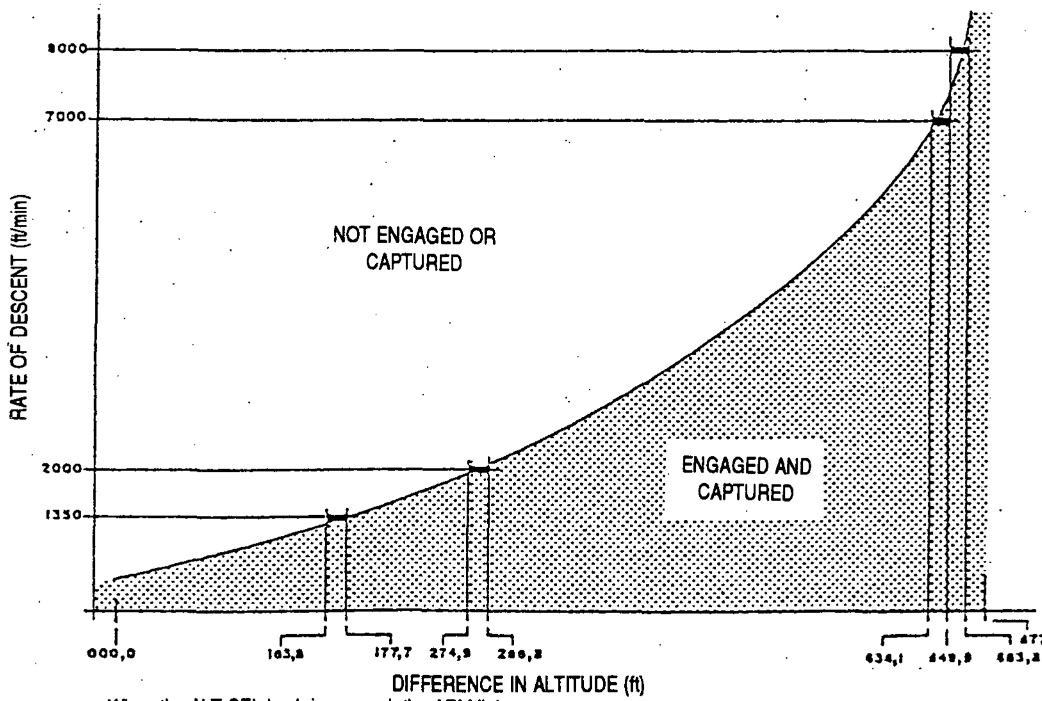
2.1 As an independent device it was observed that the operating sequence matched the description in section 1.16.2 in terms of both audible and light signals. Variations of +/- 50 ft were recorded in the operation of the signals compared with their settings. While maintaining an altitude, any change is interpreted as a deviation from the previously selected altitude. Thus by moving the dial to a new altitude we get audible and flashing light warnings.

When the system is in deviation mode, if the RESET button is pressed, it changes to approach mode and there may be a momentary audible signal.

2.2. As a system connected to the A/P, once the whole system was put through to its entire logical sequence of operations, i.e. establishing the barometric reference, setting the altitude required on the altitude selector, performing a RESET, selecting the pitch mode and arming the system, the following results could be observed:

— Once the system is armed, when pitch mode is selected (using VERT SPEED), the rate of approach to the altitude selected must be achieved in conformity with the position of the aircraft relative to such an altitude. If the aircraft is above the selected altitude, the descent rate knob needs to be turned towards the DESCEND position. If the aircraft were below the altitude selected and the knob were moved towards the DESCEND position, the system would not enter the ENGAGE phase and the aircraft would continue to descend (with the ARM light staying on).

— The ENGAGE phase starts at a point which varies according to the rate of descent and the system's calculation of the differences in altitude.



— When the ALT SEL knob is pressed, the ARM light goes on.
— ⟩—⟨ Tolerance zones.

— At the start of the ENGAGE phase the (green) ENG light comes on and the (amber) ARM light goes out, the PITCH SELECTOR control moves to the VERT SPEED position, the aircraft begins a smooth approach manoeuvre towards the altitude selected which ends at the point of capture.

— When the altitude selection equipment detects that it is between 40 and 10 feet from the altitude selected, the capture mode is activated and the A/P switches to ALT HOLD mode; the ALT SEL mode is deactivated.

— Once the ENGAGE point is reached if the VERT SPEED knob is moved, the ALT SEL mode is deactivated causing the aircraft to continue at the rate set manually.

— When ALT SEL is pressed below what is known as the point of "indecision" which is close to the ENGAGE point (about 25 to 50 feet below) the ARM armed light on the equipment comes on but the ENGAGE phase will not be activated and the amber ARM light will remain on. The aircraft will maintain its rate of descent without capturing the altitude selected and the audible and light deviation signals switch on.

Flight tests:

Tests were carried out with aircraft of the same type which were subjected to different rates of descent. The following results emerged:

— The sequence of lights and audio signals matched the description of the system above although the ENGAGED point (a function of the rate of descent and the difference in calculated altitude) differed from that observed in the behaviour of the system in the laboratory, since it used the aircraft altimeter as its reference.

— In order to perform the capture operation, the ALT SEL switch of the A/P must be selected before the ENGAGED point is reached (with a 25 ft tolerance). If it is selected later than this, the aircraft does not capture the altitude selected and continues its descent.

— If it is armed below the altitude selected, the aircraft does not climb to the altitude selected but continues its descent.

— Once armed, if the VERT SPEED control is moved during the ENGAGED phase, the capture condition is lost and the aircraft continues to descend at the rate selected manually.

— If, once armed, the A/P disengages for whatever reason, the altitude alert system remains selected but not armed. It does not recover its armed status, even if the A/P is switched in again.

— At rates of descent close to 2 000 ft/min, starting at a reference altitude with a new altitude selected and the system armed before leaving that altitude, depending on the difference between the reference altitude and the altitude selected, it was observed that:

for differences over 900 feet, when the altitude selector was adjusted to the new altitude to be captured, the 300 ft deviation audible signal switched on first and the "ALTITUDE ALERT" light signals remained off (since on the dial the shift from 300 to 900 ft is rapid and does not allow for an assessment of the operating sequence of the lights). Once 900 ft in deviation was passed on the dial, the system remained in approach mode and once armed and once the descent had started, the aircraft captured the altitude selected as per its normal sequence;

for differences equal to or less than 900 ft and greater than the point of "indecision" (around 300 ft) when the ALTITUDE SELECTOR was adjusted to the new altitude to be captured, firstly the audible 300 ft deviation warning sounded and the ALTITUDE ALERT warning lights remained on and flashing. Once armed and when descent had begun, capture of the altitude selected took place as per its normal sequence. Repeating the operation with the same difference, once the new altitude had been selected and armed, the selector button was pressed, an audible warning was heard and the system switched to approach mode so that the ALTITUDE ALERT warning lights stayed on steady. The rest of the operation continued as per the normal sequence. For differences equal to or less than 300 feet, the system does not capture since the point of "indecision" has been passed.

For higher or lower rates, the same sequences were achieved, taking into account the variation existing between their (respective) points of "indecision".

1.16.3 Reading Errors with Drum and Needle Altimeters

After consulting the extensive bibliography on the subject, the following documents were selected.

NASA TM — 81967 "How a Pilot Looks at Altitude";
NASA CR — 3306 "Instrument Scanning and Controlling: Using Eye Movement Data to Understand Pilot Behavior and Strategies";
NASA TP — 1250 "Airline Pilot Scan Patterns During Simulated ILS Approaches";
NASA CR — 1535 "The Measurement and Analysis of Pilot Scanning and Control Behavior During Simulated Instrument Approaches";
"HUMAN FACTORS IN ENGINEERING AND DESIGN'. McCormick, Ernest J.
"HUMAN FACTORS DESIGN HANDBOOK'. Woodson

From these, various paragraphs have been excerpted which may be of use in analysing this accident. Basically the first two documents have been used.

Hypothetically, a "good instrument" is one which is easy to read and offers the pilot the information sought or needed. The anemometer is a good instrument. It can be read with just one look and provides the necessary amount of information. The drum and needle altimeter is probably not a "good instrument", because it sometimes requires two looks, one to read the needle and the other to read the drum. Occasionally both can be read at the same time. At other times the pilot will read only one.

The time needed to read an instrument can theoretically be measured by recording the dwell time of the look within the borders of the instrument. In practice this is not possible since the relative importance of the information is not taken into account. In terms of human information processing, the quality of an instrument may be a factor to consider when determining the time required for the perception/cognition process as part of the cognitive work load.

The most important factor is the work load and the type of flight, depending on whether it is automatic or manual. With autopilot operation, checks are more rapid (dwell times are shorter). But the price to pay for increased speed is reduced human accuracy. This may manifest itself in two ways. When on automatic, the image of the position of the aircraft is less accurate and/or it is less likely that a significant deviation of the aircraft will be detected with automatic than with manual operation.

Another consideration is psychological doubt. Pilots' actions are predicated on what they know or think they know about the position of an aircraft. Doubts about any one parameter will increase from the moment of their last check and will be weighed up as a function of the relative importance they give to each parameter. Knowledge about the initial altitude and a constant rate of descent may produce a gradual increase in uncertainty. Because of the redundancy of the instruments, the increase in uncertainty will not necessarily depend on the time which has elapsed since the last look at any particular instrument.

Eye movement suggests that the altimeter is a low priority instrument despite instructors and pilots claiming that its priority is high.

This statement is not inconsistent with their visual behaviour if we include the secondary information available from other instruments. Altitude information may have a high priority, but uncertainty will increase slowly so that it will be held at low priority when compared with other parameters.

The level of uncertainty for a specific parameter will be a function of the pilots' memory (compared with their previous look), their integration of this information within the whole context of the image, which will depend on their most recent information from other related instruments and their prediction based on integration.

The arguments put forward here imply that the pilot could have a fairly precise knowledge of the altitude without having looked at it for some time. By measuring the accuracy of a verbal response in relation to the time since a pilot looked at the instrument, it is possible to give a reasonable indication of a pilot's uncertainty.

The tests from which the results described below were obtained were carried out on an FAA certified simulator. The only change in the instrument panel was the incorporation of an optical oculometer which was mounted below the ADF behind the panel. A television camera was mounted behind the pilot in order to be able to see the instrument panel and a television monitor was placed behind the pilot's seat to allow the test director to observe the pilot's dwell points when viewing the panel.

On ILS approach, pilots only look at the altimeter for 3 to 6 percent of the total time. Even so, they still receive information on altitude from the glide slope and the FD bars.

The result of these tests demonstrate that pilots scarcely look at the thousands of feet window (apparently because it is difficult to read) as is shown by the average dwell time of 0.6 seconds.

The design of a normal altimeter is not entirely adequate, as shown by the number of accidents/incidents caused by misreadings.

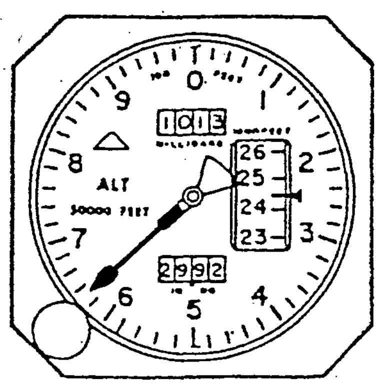
A study was carried out to ascertain the percentage of pilots who had misread or had seen other pilots misread a drum altimeter. The results, for the 169 pilots who replied were:

> 137 stated that they had misread the altimeter and 134 stated that they had observed another pilot misreading one (85% of each group said that this had happened on more than one occasion). The results of this study indicate also that a surprising number of misreadings (50) happen during the approach phase.

Some comments by pilots on the drum altimeter include:

1. "It requires more concentration to read this altimeter correctly than it ought to."

2. "The window complicates the instrument and is rather small. It often requires two looks and diverts attention away from the needle. Other instruments only need a single point of visual attention to be understood and do not divert, slow down or complicate an instrument check.



3. "Misreadings always seem to occur at low altitude when attention is divided between several activities."

4. "The greater the stress in a situation, the more the misreadings."

5. "A rapid look after (some time) can usually lead to a reading of 1 000 feet of error if the indicator is halfway between two thousands."

Pilots normally rate the altimeter as the third most looked at instrument on an aircraft (with the FD first and the anemometer second). In fact, when we asked, some pilots replied that they spent from 20 to 25 percent of their time on the altimeter. Other studies carried out with the same pilots (Ref. NASA TP-1250) indicate that for all the test conditions, on average they actually spend three to six percent of their time on the altimeter. This discrepancy between pilots' opinions and the real time they spend on the altimeter may not be as bad as it appears at first sight.

The indications are that while the pilot may be concerned about altitude for 25% of the time, this is not the equivalent of spending all of this time loking at the altimeter. On the straight and level segments of the approach phase, once the altitude is established, a pilot may use the horizontal bar of the FD to indicate position relative to the desired altitude or other signals which may indicate that a change in altitude is occurring. On starting a descent, other instruments also provide information on altitude.

To quote a NASA test pilot: "On the glideslope, the altimeter is virtually relegated. My sources of information are, first the glideslope, second the bars of the FD and third, where present, call-outs from the co-pilot". While the first two do not give absolute altitude information, they do tell the pilots where they are in relation to the desired altitude and at what point on the approach. Thus, while a pilot may in reality spend up to 25% of his/her time concerned with altitude information, it is not necessary to spend all of that time looking at the altimeter.

Results and Discussion

The references (NASA TP-1250 and NASA CR-1535) show that pilots, when flying simulated approaches, have a mean altimeter dwell time of between only 0.3 and 0.6 seconds. It was also observed that the pilot looks at the left side of the altimeter, even though the needle may be pointing to the right. This observation made it necessary to reanalyze the dwell times and to divide the altimeter into three zones, the left side, the right side and the window.

Data were taken from seven pilots who carried out a total of 108 simulated approaches.

It was noted that with short dwell times, the pilot only receives a minimum of information such as the direction in which the needle is pointing. Longer dwell times are associated with reading the needle. During the approximately 180 seconds required for an approach, the needle is only on the left side for 40 to 50 seconds (an average of 25% of the time). The pilots spends approximately 48% of the time on the left side of the altimeter. It might be presumed that the pilot can determine the position of the needle on the right side and/or its movement by looking at the left side.

The right side of the altimeter where the window is located is very important. When the pilot looks at the window and the needle overlaps this area, it is difficult to determine which part of the information is being read.

Although the drum and needle altimeter may not be the best available, all altimeters, to some extent, share the same problems. Each pilot uses a particular sequence when checking the instruments and this may vary with the type of instrumentation, aircraft and flight conditions.

The basic time required to extract the information required from an instrument such as the altimeter should be a constant for specified conditions.

The results indicate that:

1. Misreadings by pilots on drum and needle altimeters are fairly common.

2. With a drum and needle altimeter, several looks are required to gather all the available information.

3. The pilot may gather a relative position of the needle (left or right) from a rapid look (0.1 seconds).

4. The total time spent looking at the window is very short, 3% of the total devoted to the altimeter, and pilots require 0.5 to 0.6 seconds to read the window.

Many improvements could be identified such as:

a) increasing the size of the numbers on the drum (the digits are of the minimum size recommended in"HUMAN FACTORS & ENGINEERING DESIGN", McCormick, Ernest J);

b) using a meter or a combination of a meter and a drum; and

c) siting the instruments where the pilot looks most often (on the left side of the altimeter). Some of these improvements are being incorporated into some new altimeters.

1.17 Additional Information

1.17.1 Mount Oiz Antennas

At the top of Mount Oiz there was a field of antennas with the following characteristics:

a) Euskal Telebista:

Year of construction:	1982
Height of base:	1 000 m
Height:	54 m
Channel:	33 UHF
Frequency:	567 to 573 MHz (2 kW) 104.4 MHz (1 kW) 103.2 MHz (1 kW)
Markings:	Red and white painted stripes
Lighting:	Incorporated
Notice to Aeronautical Authorities:	No evidence of notice

b) Spanish Television (TVE):

Year of construction:	1971
Height of base:	1 021 m
Height:	31 m
Channel:	30 UHF
Frequency:	543 TO 549 MhZ (2 kW)
Markings:	Red and white painted stripes
Lighting:	None
Notice to Aeronautical Authorities:	Not required at time of construction

c) Communications and sound:

Year of construction:	1981
Height of base:	1 018 m
Height:	21 m
Frequency:	164 450 MHz (15 W) 163 250 MHz (10 W) 164 175 MHz (10 W) 157 650 MHz (10 W) 168 425 MHz (10 W)
Markings:	None
Lighting:	None
Notice to Aeronautical Authorities:	No evidence of notice

d) Iberduero Repeater:

Year of construction:	1979
Height of base:	1 014 m
Height:	15 m
Frequencies:	7 156-7 205 GHz (300 MW) 7 352-7 401 GHz (300 MW) 7 338-7 387 GHz (300 MW)
Markings:	Painted green
Lighting:	None
Notice to Aviation Authorities:	No evidence of notice

e) Highway assistance (DYA):

Year of construction:	1971
Height of base:	1 010 m
Height:	19 m
Power:	45 W
Frequency:	169 300 MHz
Markings:	Painted grey
Lighting:	None
Notice to Aeronautical Authorities:	Not required at time of construction

1.17.2 Bilbao Airport Approach Chart

1.17.2.1 AIP Spain Approach Chart

In 1980 a study was launched of the Bilbao Airport VOR/DME ILS-RWY 30 Approach Chart which was in force on 19 February 1985 in accordance with ICAO Doc 8168-OPS/611/3 (Aircraft Operations) of 1971 duly updated. To produce it, the data available were gathered, mainly radio aids (type and coordinates) and cartography.

DME fix point 13 (13 NM from VOR/DME BLV) was determined, located on radial 121 so that proceeding outbound, the intermediate approach manoeuvre would begin from this point moving outbound on radial 21 and then making the regulation left turn, passing over DME fix 13 again on heading 301 and starting the final approach at this point on intercepting the glideslope.

In compliance with Doc 8168 (mentioned above) the intermediate approach area was established outbound from DME fix 13, having a length of 8.5 NM and a width of 8.0 NM (5 NM from the heading on the regulation turn side and 3 NM on the other side).

According to Doc 8168, there will be no intermediate approach at an altitude less than 300 m (1 000 ft) over all the obstacles within that area.

When possible manoeuvres were examined, taking the topography of the site into account, it was observed that Mount Oiz (1 027 m) was the crucial obstacle for setting the minimum altitude on intermediate approach. That is why it was set at 1 327 m (4 353 ft).

Following the appropriate checks, the VOR/DME ILS RWY-30 approach chart was approved and published. It entered into force on 14 November, 1981. The height of Mount Oiz did not appear on the chart.

On the date of the accident, preparation of a new Bilbao Airport approach chart was being studied, in compliance with Doc 8168 (Second Edition, 1982) which had replaced all the previous editions from 25 November 1982 onwards.

1.17.2.2 Airline Approach Chart

This agreed with the AIP Spain. The height of Mount Oiz did not appear here either.

2. ANALYSIS

2.1 Flight History

IBERIA Boeing 727, registration EC-DDU, took off from Madrid/ Barajas Airport at 0747:00 on 19 February 1985 to conduct scheduled flight IB-610 with a destination of Bilbao (Sondica) Airport.

There is no evidence of any irregularity in the pre-flight preparations. It was the first flight of the day with that crew which had previously had a minimum of 24 hours of rest.

From 0755:37 (31:27)[2] when the CVR recording started, until 0757:18 (29:54) conversation took place in the cockpit between the Co-pilot and the Flight Engineer on matters to do with the service. The Captain did not participate. At the time mentioned, a member of the cabin crew entered the cockpit and was asked by all three flight crew members for coffee.

At 0758:24 (28:39) the Captain informed Control (East Take-off Sector on frequency 127.5) of passing the Arbancon NDB and leaving flight level one seven five. Control instructed him to switch to frequency one three three eight five. Once the communication was established, he reported "WE ARE LEAVING ONE EIGHT FIVE FOR TWO FOUR ZERO ON COURSE TO DOMINGO". Subsequently Control told him to switch to Madrid Sector on frequency one three four three five.

At 0759:33 (27:10) contact was established with Bilbao Sector and the following communications took place until 0800:13 (26:51):

2. Note that the figures in brackets are the time in minutes and seconds to impact.

C1: "MADRID IBERIA SIX ONE ZERO GOOD MORNING"

LECM: "SIX ONE ZERO MADRID, GOOD MORNING, RADAR CONTACT. WHAT LEVEL DO YOU WISH?"

C1: "TWO SIX"

LECM: "SIX ONE ZERO CLEARED FOR FLIGHT LEVEL TWO SIX ZERO"

C1: "O.K. FOR TWO SIX ZERO. WE ARE NOW LEAVING TWO ONE FIVE, THANK YOU".

LECM: "ROGER"

Analysis of the FDR (Flight Data Recorder) shows that the communications data match the movements of the aircraft in heading, altitude and position.

There were no further communications until contact was made with the airline's operations in Bilbao.

While the aircraft was climbing to reach the cruising level, unimportant conversations continued in the cockpit between the Co-pilot and the Flight Engineer.

At 0812:18 (24:46) the altitude alert buzzer can be heard on the CVR, warning that the system was approximately 900 feet from capturing level two six zero as intended. Nineteen seconds later the throttle back audible warning sounded with the aircraft at the cruising level, probably as a result of switching the PDC selector from CLIMB to CRUISE and setting a lower speed than climb on the anemometer.

At 0807:41 (19:22) the Co-pilot reported the flight data to Airline Operations Bilbao, gave the estimated time to landing, 17 minutes, and requested airport meteorological information. From that time onwards all communications with both Operations and the Control Centres were carried out by the Co-pilot. The information he received from Operations was as follows: "WIND ONE HUNDRED AND TEN DEGREES, FOUR KNOTS, VISIBILITY FOUR KILOMETRES REDUCED BY FOG AND TWO OF CUMULUS AT TWO THOUSAND FIVE HUNDRED, FOUR OF STRATOCUMULUS AT FOUR THOUSAND, TEMPERATURE SEVEN, DEW POINT SEVEN AND QNH ONE THOUSAND AND TWENTY FIVE ONE ZERO TWO FIVE.

At 0809:29 (17:34) the following communication took place:

C2: "MADRID, SIX ONE ZERO READY FOR DESCENT."

LECM: "SIX ONE ZERO, CLEARED FOR FLIGHT LEVEL ONE THREE ZERO, OVER, CORRECTION ONE ZERO ZERO"

C2: "TO ONE HUNDRED, COPIED. LEAVING TWO SIX."

The altitude alert warning signal is heard immediately probably because level one zero zero for which they had been cleared was being selected.

Then a member of the cabin crew entered. Although her question was unintelligible, from the Co-pilot's reply, "FIFTEEN MINUTES, SEVEN DEGREES, LIGHT FOG" it can be deduced that she was seeking information to pass on to the passengers. This was then announced in both English and Spanish on the PA.

From 0810:16 (16:48) to 0811:01 (16:03) a conversation took place in the cockpit between one member of the cabin crew and the three members of the flight crew. It can be deduced that the coffees requested earlier were being brought.

At 0812:13 (14:51) noises which can be identified as the frequency selector are heard on the CVR and immediately afterwards the NDB-BIL morse signal can be heard. Even though communications between other traffic on the same frequency and Madrid Control are perceptible, no conversation can be heard in the cockpit until Madrid addressed the aircraft and the following exchanges take place:

LECM: "IBERIA SIX ONE ZERO, CONTACT BILBAO APPROACH NOW. GOOD-BYE. ONE HUNDRED EIGHTEEN FIVE."

C2: "GOOD-BYE."

At 0816:03 (11:00)

C2: "BILBAO TOWER, GOOD MORNING SIX ONE ZERO."

TWR: "IBERIA SIX ONE ZERO, GOOD MORNING, OVER".

C2: "WE ARE LEAVING LEVEL ONE THREE FOR LEVEL ONE HUNDRED TWENTY EIGHT, OUT."

TWR: "ROGER IBERIA SIX ONE ZERO. ONE MOMENT PLEASE."

TWR: "IBERIA SIX ONE ZERO, YOU MAY CONTINUE DESCENT FOR AN ILS APPROACH TO BILBAO RUNWAY THREE ZERO. WIND ONE HUNDRED DEGREES THREE KNOTS, QNH ONE ZERO TWO FIVE AND TRANSITION LEVEL SEVEN ZERO."

C2: "THANK YOU, DESCENDING TO SECTOR MINIMA ON ONE THOUSAND AND TWENTY FIVE."

TWR: "CORRECT. ONE THOUSAND AND TWENTY FIVE AND IF YOU WISH YOU MAY PROCEED DIRECT TO THE FIX."

0816:54 (10:09) (ALTITUDE ALERT BUZZER)

C2: "WE ARE GOING TO EXECUTE THE STANDARD... MANOEUVRE."

TWR: "ROGER, NOTIFY PASSING OVER THE VOR."

The sound of the altitude alert buzzer occured on selection of level seven zero which was the sector minimum and coincided with the transition level.

At 0817:49 (9:15) the Co-pilot said "TEN THOUSAND DESCENDING" and the Flight Engineer began reading off the ten thousand feet list ending at 0819:45 (7:18), except the seatbelts. Clearly audible on the CVR are the voices of the Co-pilot and the Flight Engineer but not the Captain.

At 0820:23 (6:41) the altitude alert buzzer can be heard which in line with the FDR data corresponds to the system warning approaching level seven zero.

At 0820:32 (6:32) the throttle back buzzer sounded. The IAS was then 260 knots. It is felt that the crew throttled back and reduced the rate of the descent to cut speed and initiate the flaps sequence.

At 0821:40 (5:24) the Co-pilot said "TWO PLEASE" and 14 seconds later the Flight Engineer replied, "TWO GREEN, ONE NINE...MIN". This corresonds to requests for two degrees of flaps and confirmation that they were already extended symmetrically and at the same time provides the minimum speed for this position of the flaps.

At that moment the aircraft heading was 006° towards the Bilbao VOR with an approach altitude of 7100 feet and an IAS of 215 knots.

At 0822:04 (05:00) the Co-pilot announced to TWR: "SEVEN THOUSAND FEET OVER THE VOR, IBERIA SIX ONE ZERO. INITIATING MANOEUVRE." This was the last communication from the aircraft. Immediately TWR replied: "ROGER SIX ONE ZERO". When the Co-pilot began his communications the aircraft heading was 006°, altitude 7,000 feet and IAS 211 knots. At the moment at which it received the reply from the TWR it started a turn to the right towards heading 084° and immediately, before the aircraft was stabilized selected a new heading which brought it to 130°.

During the turn, until it reached a heading of 125°, the aircraft maintained its altitude of 7 000 feet and an IAS of 204 knots. At that time, 12 seconds before leaving 7 000 feet, the altitude alert buzzer sounded. This is thought to correspond to the selection of 5 000 feet in line with the approach chart, subsequent manoeuvres by the aircraft and warnings from the altitude alert system.

At 0823:14 (03:50) they left 7 000 feet.

From the time of leaving 7 000 feet until reaching 5 000 feet at 0825:14 (01:50) the aircraft descended at a rate of 1 000 feet per minute, the IAS fluctuated between 198 and 214 knots and, after reaching 130° the heading shifted to 113°. Subsequently a further correction towards 124° began and when the aircraft reached 5 000 feet the heading was 117°. During descent from 7 000 to 5 000 feet the Co-pilot can be heard on the CVR saying at 0824:00 (03:04) "LET'S SWITCH SEAT BELT SIGNS ON NOW". This was done immediately since the passenger warning signal is heard. Eleven seconds later the request to passengers to fasten their seat belts is heard in both English and Spanish over the PA.

At 0824:27 (02:37) the altitude alert warning sounded, coinciding with the 900 feet from 5 000 feet warning which it is thought was selected before leaving 7 000 feet, when the sound of the signal was heard.

At 0825:14 (01:50) the aircraft reached 5 000 feet and until leaving this level 25 seconds later, the heading varied from 117° to 124°, IAS reduced from 209 knots to 203. At 0825:30 i.e. nine seconds before leaving 5 000 feet, the altitude alert system signal sounded, probably on selection of 4 300 feet.

At 0825:39 (01:25) the aircraft left 5 000 feet descending at 1 500 ft/min which it maintained until it reached an altitude of 3 870 feet 48 seconds later and changed to 700 ft/min which it maintained virtually until impact. From the time of leaving 5 000 feet until the collision, the speed was maintained between 203 and 213 knots.

Five seconds after leaving 5 000 feet the aircraft began a change of heading to the left which took it from 124° to 078° at the moment of change of rate of descent and which continued to vary slightly until it reached 076° 10 seconds before impact; immediately afterwards it began a right turn until it reached a heading of 096° when the impact with the televion antenna mast occurred.

Forty one seconds after leaving 5 000 feet and forty four before impact, at an altitude of 4 040 feet the altitude alert buzzer had sounded which, according to the logic of the operation of the system only sounds at 900 feet from the altitude selected on approach and/or 300 feet after passing it. It must be supposed that 4 300 feet had been selected since a selection of 3 100 feet which would have caused the signal to sound in approach mode (900 feet from the altitude selected) does not correspond to any value on the chart. On the contrary, selection of 4 300 feet is logical. Since the selection between 5 000 and 4 300 feet is less than 1 000 feet, the system signal would not sound in approach mode and would sound at approximately 4 000 feet in deviation mode (300 feet away from the altitude selected).

At 0826:54 (00:10), which coincides with the start of the turn to the right, the Co-pilot said: "FIVE PLEASE".

Two seconds later: "MINIMUM, ONE SIX ...THREE. FOUR THOUSAND THREE HUNDRED, TURN."

The first phrase corresponds to the request for five degrees of flaps. The second to a comment or reading of the minimum speed for this condition and minimum altitude for the turn of the manoeuvre in line with the interpretation of the chart rounding off the altitude (4 354 feet) incorrectly or by having read it on the display of the altitude alert system. Immediately after the end of the Co-pilot's phrase, the sound of the impact of the aircraft with the antenna mast can be heard at 0827:04.

2.2 Actions of the Crew

2.2.1 Pilot at the Controls

It is common practice when several stops are to be made on one day, for each crew member to conduct one complete leg.

According to the CVR, communications during the climb were conducted by the Captain, leading to the supposition that he was not the pilot at the controls. On the CVR recording no warning is heard of 1 000 feet for the level. Except for brief comments, he did not participate in conversation with or make any verbal comments to the Co-pilot about the conduct of the operation.

Although communications with Airline Operations in Bilbao and subsequently with Madrid Control and Bilbao TWR were conducted by the Co-pilot, these were very short and took place in the cruising and descent phases. Moreover the frequencies used were quite free of communications with other traffic.

Nonetheless, it seems that the level or altitude settings on the altitude alert system were made by the Captain. This may have been a way of directing the operation without feeling it necessary to give audible instructions. The setting of the altitude alert system and the warnings of the system approaching the levels or altitudes selected may have made the Captain feel it was unnecessary to make the 1 000 feet call outs.

It is thought that it was the Captain who made the settings and armed the altitude alert system because according to statements from other airline crew members, this was his usual practice. In addition, on two occasions when the system warning sounds for a new setting it is difficult to imagine that at the same time as the Co-pilot was transmitting, he was setting the altitude alert, system which, given its location on the centre pedestal, is not an easy operation.

The landing estimates given to Airline Operations and to the cabin crew member of 17 and 15 minutes respectively (given two minutes apart) were given by the Co-pilot.

Normally changes in configuration (flaps, gear, etc.) are requested by the pilot at the controls. In this case, it was the Co-pilot who requested two and five degrees of flaps. The audible warning to passengers to put on their belts coincided with the comment from the Co-pilot "LET'S SWITCH SEAT BELT SIGNS ON NOW". Bearing in mind that this was the item needed to complete the 10 000 feet check list and since the sentence was not phrased as a question, it must be supposed that the Co-pilot carried out this action.

From all the above it can be deduced that the Co-pilot was at the controls.

2.2.2 Descent from the Cruising Level to 5 000 feet

In line with the data obtained from the FDR, time synchronisation with the CVR and the reconstruction of the flight path, it can be determined that after overflying the DOMINGO waypoint at the cruising level and once clearance had been granted by Control to start the descent, the Co-pilot maintained speeds, heading and rate of descent consistent with the most suitable for the conduct of this part of the flight.

Its rates of descent from cruising level were 2 500 ft/min to around level 190, something less than 2 000 ft/min to approximately level 100 where the rate was cut to 750 ft/min until the altitude alert system warning sounded (900 feet away from 7 000 feet which was the last altitude selected) where it reduced to 600 ft/min and more or less simultaneously the thrust levers were pulled back to reduce the IAS, which at that time was 260 knots, and to be able to reach 210 knots at 7 000 feet.

Communications with both Madrid Control and Bilbao TWR are perfectly in line with the levels the aircraft was reaching or leaving.

Settings on the altitude alert system were achieved as soon as Control clearances for new levels were received.

When the Co-pilot communicated with TWR that they had reached 7 000 feet, the aircraft was indeed at that altitude around 4 NM from the VOR and it immediately started a right turn towards capturing an outbound heading. When it completed the turn it maintained a flight path broadly parallel to the corresponding radial, apparently converging towards NDB-BIL.

Nine seconds before leaving 7 000 feet the altitude alert system warning can be heard on the CVR, corresponding to 5 000 feet which was the altitude required for DME fix 13. Afterwards during the descent to 5 000 feet, at 900 feet away, the altitude alert system warning is heard again. This warning matches the operation of the system in its approach mode to the altitude selected.

The rate of descent between 7 000 and 5 000 feet was 1 000 ft/min.

2.2.3 Manoeuvres made from 5 000 feet to Impact

Once the aircraft had levelled off at 5 000 feet and before leaving that altitude, the altitude alert system warning is heard again as a result of adopting a new setting.

One feature of the altitude alert system is that it is not possible to select values of less than hundreds of feet. The correct selection should have been 4 400 feet since the minimum altitude indicated on the chart is 4 354 feet.

At or close to DME fix 13 the aircraft started its descent as well as a left turn on heading 076° as established on the chart for the straight section of the procedural turn.

Taking into account that the intermediate approach protection area starts at the outbound fix and even though the established manoeuvre indicates that an outbound direction should be maintained until the minimum altitude is reached, the beginning of the procedural turn at this point may be considered acceptable.

From the time at which the aircraft left 5 000 ft, a rate of descent of 1 500 ft/min was maintained for 48 seconds bringing it to a altitude of 3 870 feet at which point it changed to a rate of 700 ft/min which it maintained effectively for the last 37 seconds until impact.

2.2.3.1 Phase of the Flight below the Minimum Altitude for the Intermediate Approach Manoeuvre

Since no conversation was recorded on the CVR (from before leaving 5 000 ft until the request by the Co-pilot for 5° of flaps, 10 seconds before impact) which indicates an intention to conduct this phase of the flight as it occurred, there is a need to examine the reasons for the crew being led to fly inadvertently below the minimum manoeuvre altitude.

In line with the analysis carried out, such a situation could have arisen from:

a) erroneous action as a response to incorrect or mistaken knowledge of the real situation which was aggravated by

b) response to the altitude alert system warnings, and

c) misreading the altimeter.

1) On reaching the starting point of the intermediate approach manoeuvre it is only necessary to descend 600 feet if 4 400 feet has been set on the altitude alert system or 700 feet if 4 300 feet has been set. This seems to have been the setting chosen by the crew.

   Taking into account that the rates of descent studied previously, except for that when leaving the cruiseing level and up to level 100 were lower than 1 500 ft/min and that it had the whole time of the procedural turn or at least the segment prior to the turn in order to reach the minimum manoeuvre altitude, and that it started this segment 10 seconds before impact and seventy five seconds after leaving 5 000 feet, the rate of descent may be explained by the fact that the Co-pilot felt that he was starting at an altitude other than 5 000 feet.

   At the time of the accident it was not uncommon when approaching Bilbao to proceed directly to DME fix 13 either at the request of the crew or because the TWR so instructed it, if traffic allowed. The direct manoeuvre to the fix avoided overflying the Bilbao VOR with consequent time savings, without endangering safety as long as an aircraft did not descend below the minimum sector altitude which was 7 000 feet.

   On this flight it was TWR which informed the aircraft when it was leaving level one three zero and at 28 miles from the VOR, i.e. at three miles from the sector limit, that it could continue its descent for an ILS approach and proceed directly to the fix, if it so wished.

   From the Co-pilot's reply and subsequent comments in the cockpit, it may be deduced that the Co-pilot intended to head for the fix but that probably because of some signal or gesture from the Captain, communicated that they were going to undertake the standard manoeuvre.

   At that moment there might have been some mental conflict between the wish of the Co-pilot to conduct a shorter flight, since TWR had cleared it and the indication from the Captain to conduct the standard procedure. The difference between the two lies in the fact that the manoeuvre of proceeding direct to the fix requires reaching it at 7 000 feet and the standard manoeuvre allows it to reach 5 000 feet at the same point.

   Consequently for a setting of 4 300 feet on the altitude alert system, for the former it would be necessary to descend 2 700 feet as against 700 feet for the latter on an intermediate approach manoeuvre.

   The setting made by the Captain on the altitude alert system plus the fact that he did not provide 1 000 feet call-outs for the level, together with the continuous silence in the cockpit especially during the last six minutes of the flight, may have meant that when the aircraft reached DME fix 13 (bearing in mind that they had received clearance for this, even though they had not accepted it) the Co-pilot was led to believe that he had reached this point by the manoeuvre which he had planned mentally and to act from that moment as if he were at 7 000 feet, the minimum altitude at DME fix 13 if one is approaching it directly. This may have led to his descending at a rate of 1 500 ft/min to reach the altitude required for the intermediate approach manoeuvre.

2) The altitude alert system has two types of warning signals, audible and visual (light). If the "ALT SEL" button located on the A/P centre control pedestal is pressed, only the audible and visual warnings prior to capture of the altitude selected will be activated (as long as the setting made is 1 000 feet or more away from the current altitude and that selected).

If the system setting is less than 1 000 feet away and the system is not reset, the system will continue with the flashing light of the previous setting on and this will switch off at 300 feet before the altitude selected and, in line with the studies carried out, will capture it if it is armed. Otherwise descent will continue and it will give an audible warning 300 feet after the altitude selected at the same time as the flashing light for leaving altitude selected switches on and will switch off 900 feet later.

In line with the FDR, CVR and examination of the wreckage, it can be stated that nine seconds after leaving 5 000 feet, a setting was made on the altitude alert system. The equipment was found with the thousands figure stuck on four, the hundreds showed three and only allowed movement between two and three and the audible warning would only sound when the aircraft was at an altitude very close to 4 000 feet.

Actions on the system and its response might have occurred as follows:

i) The Captain selected 4 300 feet on the altitude alert system. Inadvertently he might not have pressed the "ALT SEL" switch or, once it was pressed, one of the pilots might have pressed it again so that the system disarmed and did not capture the altitude.

ii) The Co-pilot might have had his hand on the centre pedestal, impeding the Captain's normal action of pushing the "ALT SEL" switch and when he did press it, the limit for capture had already been passed.

iii) The system had worked correctly for previous captures at 7 000 and 5 000 feet although a malfunction cannot be ruled out for this capture.

In any one of these cases, when leaving 5 000 feet the first audible warning which the system would give for having selected a difference of less than 1 000 feet would be the audible 300 feet warning following the altitude selected and a warning light on the front panel would flash. This would occur at 4 000 feet and the flashing light would have continued until an altitude of 3 400 feet. The visual warning might not have been significant and might not have fulfilled its alarm function since the indicator is the same for both approach to and departure from the altitude selected.

Consequently the Co-pilot must have interpreted the audible warning of the altitude alert system as being the approach to the altitude selected. His actions were similar to those he undertook when he heard the 7 000 feet audible approach warning and was about to start the turn over the VOR, reducing the rate of descent, which he maintained until impact, while waiting for the A/P to capture the altitude selected, 4 300 feet.

3) This aircraft was equipped with what are known as drum and needle altimeters. The instrument is sited approximately 70 cm from the pilot's eyes and slightly offset to the right. It has a diameter of 69.7 millimetres and is divided into 10 sectors of one hundred feet numbered from zero to nine and

with twenty-foot subdivisions. On the right semi-circle it has a window in which the figures for the thousands of feet appear from top to bottom in decreasing order. This window, which allows for up to four figures to be displayed, has a fixed pointer arrow on its right side.

To carry out a reading, it is necessary to take the lower of the two figures which are closest to the arrow on the thousands window and add them to the hundreds and tens of feet shown by the needle.

The results of the tests carried out on drum and needle altimeter misreadings showed that pilots hardly look at the thousands window (apparently because it is difficult to read), average dwell time for reading the altitude is 0.6 seconds.

From the NASA study to find out the percentage of pilots who had misread or had seen other pilots misread the drum altimeter, the following data were obtained: of the 169 pilots who replied, 137 stated that they had misread the altimeter and 134 stated that they had seen other pilots misread it (85% of each group said that it had happened to them on more than one occasion). In other studies carried out by NASA it was felt that pilots' movements are predicasted on what they know or think they know about the position of the aircraft. Knowledge about the initial altitude and a constant rate of descent at any particular moment, may produce a gradual increase in uncertainty and make them forget the need to look at the altimeter.

This situation of false confidence is supported by conducting the flight on autopilot. As was shown in the studies quoted, when flying on automatic, it is less likely that they would detect a significant deviation of the aircraft.

The comments about drum altimeters by the pilots which concur with the studies referred to, should be remembered:

> "It requires more concentration to read this altimeter properly than it ought to".
>
> "The window complicates the instrument and is rather small. It often requires two looks and diverts attention away from the needle. Other instruments only need a single point of visual attention in order to be understood and do not divert, slow down or complicate an instrument check."
>
> "Misreadings always seem to occur at low altitudes when attention is divided between several activities."
>
> "The greater the stress in a situation, the more the misreadings."
>
> "A rapid look after (some time) can usually lead to a reading of 1 000 feet of error if the indicator is halfway between two thousands".

The fact that the aircraft remained below the altitude selected for 55 seconds and thus below the manoeuvre protection limits for 57 seconds leads one to believe that any reading that was carried out must only have taken into account the altimeter needle without specifically looking at the thousands window. A correct reading would have shown in the first 30 seconds after leaving 5 000 feet, the proximity to 4 300 feet (the altitude selected on the altitude alert system and one to which the Co-pilot referred three seconds before impact) and subsequently that it was flying below that altitude.

3. CONCLUSIONS

3.1 Findings

1. The Captain and the other members of the crew were adequately qualified and experienced.

2. The Controller was adequately qualified, experienced and physically fit.

3. The aircraft held valid Airworthiness, Registration and Maintenance Certificates. The files show that it had been maintained according to the authorized maintenance programme.

4. The navigation and approach aids were operating correctly according to the checks carried out.

5. There is no evidence of any malfunction of the ATC communications equipment.

6. No evidence of any abnormality in the operation of the aircraft engines or systems was revealed by the investigation.

7. The mass and centre of gravity were within established limits.

8. For its last 57 seconds the aircraft was flying below the altitude established for the manoeuvre which it was conducting.

9. Given the progress of the flight, the crew either did not carry out the altitude checks correctly or their readings were wrong.

10. The operating philosophy of the altitude alert system does not allow for a crew to relax its vigilance with respect to the flight altitude, trusting that the altitude selected is going to be captured by the A/P.

11. When setting the altitude alert system the crew made the error of rounding the altitude figure of 4 354 feet down to 4 300 instead of rounding it up to 4 400.

12. There was insufficient supervision of the manoeuvre by the Captain who was not at the controls, nor did he provide the 1 000 feet call-outs on approaching the different altitudes.

13. The television antenna mast with which the aircraft collided was over 28 metres above the top of the mountain and, even though it did not appear on the chart, it should have been the critical obstacle for calculating the safe altitude for the intermediate approach manoeuvre protection area.

3.2 Cause

Because of their confidence in the automatic capture by the altitude alert system, incorrect interpretation of its warnings as well as a probable misreading of the altimeter, the crew was flying the aircraft below the safe altitude where it collided with a television antenna mast, lost its left wing and struck the ground out of control.

4. RECOMMENDATIONS

1. Reiterate to flight crews the need for and importance of the pilot who is not at the controls to carry out the call-outs of the minimum altitudes (ATC authorized, sector, over radio aids, procedural turn, etc.).

2. Reiterate to and instruct flight crews about the importance of and need for training covering cockpit co-ordination and resource management.

3. Replacement of drum and needle altimeters by other models which would, insofar as possible, avoid misreadings.

4. Remind flight crews of the need to read the thousands window carefully on drum and needle altimeters.

5. Study changing the audible warning on the altitude alert equipment for leaving the altitude selected to an intermittent signal synchronised with the system's light signal and ensuring that the arming of the automatic capture be permanent (except when the A/P is in Auto G/S mode).

6. Urge the aeronautical authority concerned to speed up the updating of aeronautical charts to comply with the Standards of ICAO Doc 8168 which is in force.

7. Insist that when flight crews are setting the altitudes which appear on the approach charts on the altitude alert equipment windows, they should always round the figures upwards to the nearest hundred.

8. Urge the aeronautical authority concerned to conduct systematic, periodic inspections of the specific areas which have protection areas to avoid obstacles appearing which exceed the maximum permitted heights.

ICAO Note.— Appendices were not reproduced.

ICAO Ref.: 021/85

No. 2

Boeing 747 SP, N4522V, accident 300 NM northwest of San Francisco, United States, on 19 February 1985. Report No. NTSB/AAR-86/03 released by the National Transportation Safety Board, United States

SYNOPSIS

About 1016 Pacific standard time, February 19, 1985, China Airlines Flight 006, a Boeing 747 SP-09, enroute to Los Angeles, California from Taipei, Taiwan, suffered an inflight upset. The flight from Taipei to about 300 nmi northwest of San Francisco was uneventful and the airplane was flying at about 41,000 feet mean sea level when the No. 4 engine lost power. During the attempt to recover and restore normal power on the No. 4 engine, the airplane rolled to the right, nosed over, and entered an uncontrollable descent. The captain was unable to restore the airplane to stable flight until it had descended to 9,500 feet. After the captain stabilized the airplane, he elected to divert to San Francisco International Airport, where a safe landing was made. Although the airplane suffered major structural damage during the upset, descent, and subsequent recovery, only two persons among the 274 passengers and crew on board were injured seriously.

The National Transportation Safety Board determines that the probable cause of this accident was the captain's preoccupation with an inflight malfunction and his failure to monitor properly the airplane's flight instruments which resulted in his losing control of the airplane.

Contributing to the accident was the captain's over-reliance on the autopilot after the loss of thrust on the No. 4 engine.

1. FACTUAL INFORMATION

1.1 History of the Flight

China Airlines Boeing 747 SP-09, Flight 006, was a regularly scheduled passenger flight between Taipei, Taiwan, and Los Angeles, California. Flight 006 departed Taipei at 0022 Pacific standard time 1/ (1622 Taipei local time), February 19, 1985, with 251 passengers and 23 crewmembers on board.

The flight was uneventful until just west of reporting point Redoo, about 300 nmi northwest of San Francisco, California. Flight 006 was at flight level (FL) 410 2/ and was estimating Redoo at 1013. The flight was above a lower cloud layer

1/ All times herein, unless otherwise specified, are Pacific standard time based on the 24-hour clock.

2/ A level of constant atmospheric pressure related to a reference datum of 29.92 in Hg. FL 410 represents a barometric altimeter reading of 41,000 feet.

whose tops were reported to be at or about 37,000 feet. 3/ The airplane's autopilot was engaged and was operating in the Performance Management System (PMS) mode. The PMS was providing pitch guidance and maintaining a selected 41,000 feet; roll guidance to the autopilot was provided by the Inertial Navigation System (INS). The autopilot uses only the airplane's ailerons and spoilers for lateral control; it does not use the airplane's rudder and rudder trim for this purpose. The PMS also was maintaining 0.85 Mach (M), 254 knots indicated airspeed (KIAS), by providing thrust setting commands to the airplane's autothrottle system servomotor. According to the flightcrew, as the airplane approached Redoo, it began to encounter light clear air turbulence. The airspeed began fluctuating between about 0.84 (251 KIAS) and 0.88M (264 KIAS) and the PMS began moving the throttles forward and aft to maintain the commanded cruise Mach number (0.85M).

About 1010, the Mach number increased to about 0.88 M, the PMS retarded the throttles, engine thrust decreased to about 1.0 EPR 4/, and the airplane began decelerating. As the airspeed reached about 0.84M, the PMS moved the throttles forward. Engines 1, 2, and 3 responded to the movement of the throttles and began accelerating; however, the flight engineer said that the instrument gauges of the No. 4 engine did not indicate a corresponding acceleration. The flight engineer then moved the No. 4 throttle forward and aft manually, but he said that he did not see any corresponding indication of engine response to the throttle movements on the applicable engine instruments. At the time this occurred, the flight engineer said that the four main tanks were supplying fuel directly to their respective engines. The No. 2 main tank was pressurizing the fuel crossfeed system; all other fuel tank crossfeed valves were closed. The automatic fuel heating system was on. In addition, the captain had turned the "fasten seatbelt" signs on when the flight had encountered the clear air turbulence. In accordance with company procedures, the flight engineer had placed the ignition switches in the "flight start" position, thereby providing continuous ignition to all four engines. At the time of the occurrence, and in accordance with the company's procedures, two of the airplane's three air conditioning packs were on and set to the "half flow" position.

The captain said that he observed the flight engineer move the No. 4 throttle. He said that he did not "feel" anything unusual when the No. 4 engine did not accelerate; he just noticed that the No. 4 engine's instrument gauges were not responding to the throttle movements and that the indicated airspeed began decreasing.

Shortly thereafter, the flight engineer told the captain that the No. 4 engine had flamed out. The flight engineer said that he also noted that the No. 4 generator breaker open light on the electrical section of the flight engineer's instrument panel was lit, indicating that the No. 4 generator control breaker had opened and the generator was no longer on-line. Thereafter, in response to the captain's command, he took out his checklist to review the applicable engine out procedures and the airplane performance charts to ascertain the three-engine enroute cruise altitude. The captain directed the first officer to request a lower altitude from air traffic control (ATC) in order to descend and to restart the engine. Although the maximum engine restart altitude is 30,000 feet, the captain directed the flight engineer to try to relight the No. 4 engine while at 41,000 feet. The flight engineer placed the engine's No. 2 ignition switch to the "flight start" position, thus putting both ignition systems on the No. 4 engine in continuous ignition. (Only one of the two ignition systems are used during normal operations.

3/ All altitudes herein, unless otherwise specified, are mean sea level altitudes.

4/ Engine Pressure Ratio. EPR is the turbine discharge total pressure divided by total pressure at the compressor inlet; the higher the EPR, the greater the engine thrust output.

According to company procedures, the No. 1 system is used eastbound and No. 2 westbound.) The attempt was unsuccessful and the airplane continued to decelerate.

The first officer heard the flight engineer tell the captain that the No. 4 engine had flamed out and he told the relief flight engineer to come forward and help the "on duty" flight engineer. He saw that the airspeed was decreasing and he informed the captain of the situation. At 1014:11, he requested a lower altitude from the Oakland, California, Air Route Traffic Control Center (ARTCC). He did not tell Oakland ARTCC about the engine failure, nor did he declare an emergency. The first officer said that Oakland ARTCC told him to "stand by" and he did not recall hearing anything further in response to his request. However, the ATC transcript showed that, at 1015:01, Oakland ARTCC had cleared the flight to descend to and to maintain FL 240 and that Flight 006 did not acknowledge the clearance. In addition, between 1015:13 and 1016:28, Oakland ARTCC tried unsuccessfully six times to contact Flight 006.

The captain said that the airspeed dropped through 240 KIAS, and, as the airplane continued to decelerate, he turned the autopilot's speed mode selector switch from PMS to "OFF" to release it from the altitude hold command. This switched the autopilot to the pitch attitude hold mode while maintaining the INS track in the autopilot roll mode without any pilot input. He then rotated the pitch control wheel on the autopilot manual control module in the nose-down direction to begin a descent to arrest the airspeed loss; however, the captain said that the airspeed continued to decrease and so he disengaged the autopilot to lower the airplane's nose manually at a faster rate in a further attempt to arrest the airspeed loss.

The first officer stated that he "looked up" after he completed his radio call and saw that the airplane had banked "slightly" to the right. He said that he saw the captain disconnect the autopilot, that the airplane continued to bank to the right, and that he "told the captain it was banking right."

The captain said that after he disengaged the autopilot the airplane yawed and rolled further right and that the first officer told him that the airplane "was banking right." He said that while he was concentrating on his attitude director indicator (ADI) to make a left-wing-down correction, the instrument's background, which contained the horizon reference line, rotated rapidly to the left and the horizon reference line rolled to the vertical position. The captain said that he did not see any failure flags or lights on his ADI and when he looked over at the first officer's ADI and the standby ADI 5/, they looked the same as his. By this time, according to the captain, the airplane had entered the clouds, and he didn't know what attitude it was in.

The captain said that about the time the ADIs rotated, the flight engineer told him that the other three engines had lost thrust and that the "airplane dropped all of a sudden." He pulled back on the control column, but the indicated airspeed continued increasing rapidly until it exceeded the airplane's maximum operating speed (Vmo) 6/. During this part of the "upset," the first officer said that his ADI had rotated to the left in the same manner as the captain's and that he did not see any ADI failure flags or lights. He said that, at that point in the flight, he saw that both the captain's and his ADIs "had malfunctioned," that the airplane was out of control, banking left and right, and that he felt that it was in a steep bank.

5/ The captain's, first officer's, and standby ADIs are unrestricted in the roll mode and have a 90° pitch limit.

6/ Vmo is 378 KIAS at sea level and increases to 394 KIAS at 24,500 feet. Above 24,500 feet, Vmo is 0.92M.

The flight engineer said that he felt the airplane enter an abnormal attitude, he heard the captain report that his ADI was lost, and he saw the standby ADI "going out of limits." He said that the airplane was descending and the captain was trying to recover when he saw the No. 1, 2, and 3 engines had lost thrust. After telling the captain, he moved the three throttles forward and aft, but he did not observe any corresponding indications of thrust response on the engine's instruments. He placed the standby ignition switch "on" but there was no engine response. Thereafter, the G forces became so great that he could not lift his arms and his head was forced down against the center control pedestal. (The standby ignition switch uses the standby bus alternating current (a.c.) electrical power. The standby a.c. bus is normally supplied by the essential a.c. bus. As an alternate, the power can be supplied from the battery/static inverter. Placing the selector switch to either the "IGN 1" or the "IGN 2" position provides continuous ignition to all engines through the selected igniter when the start levers are in the rich or idle position.)

The captain stated that he was unable to recover the airplane while it was in the clouds; he was uncertain of its roll attitude and was moving the control wheel to the left and to the right. However, as the airplane accelerated, the captain said he continued to pull the control column back and the airplane began to decelerate rapidly. The captain said that the airspeed decreased to between about 80 to 100 KIAS and, at that point, he lowered the airplane's nose, the airplane accelerated, and the indicated airspeed again exceeded Vmo. The captain, then assisted by the first officer, pulled the control column back and the airplane decelerated. The captain lowered the nose smoothly. The airplane began accelerating slowly and as it did so, it emerged from the clouds. The captain told the flightcrew that he could see the horizon outside the airplane. The captain, first officer, and flight engineer said that they did not hear the overspeed aural warning and that the stall warning stickshaker did not activate at any time during the descent.

As the airplane emerged from the clouds at about 11,000 feet it was, according to the captain, accelerating through 180 KIAS. The captain, based on outside visual references, began regaining control and was able to finally stabilize the airplane at about 9,500 feet. The first officer said that he saw his ADI was "coming back" just before the captain announced that he could see the horizon outside the airplane. The flight engineer also noted that he saw the first officer's ADI "coming in" at this time.

As the airplane descended through 10,000 feet, the flight engineer said that the Nos. 1, 2, and 3 engines "came in," but the No. 4 engine did not start. When he placed the No. 4 ignition switch in the ground start position, however, the engine did start. According to the flight engineer, the restart of the No. 4 engine was accomplished in accordance with checklist procedures.

The flight engineer stated that he did not think that the airplane lost a.c. electrical power during the upset and subsequent descent. He said that he had not seen any instrument warning flags during the entire episode and that, "If we had lost electrical power we would have seen flags." According to the flight engineer, after all the engines had started, he checked the electrical control panel, and, except for the fact that the No. 4 generator open light was lit, all other lights were out and "everything was normal." He closed the No. 4 generator control breaker, the light went out, and the generator came on line.

After the airplane was stabilized, Oakland ARTCC was contacted, and, at 1017:03, Flight 006 reported that it had experienced a "flameout, ah, we emergency. . . .we are niner thousand feet. . ." Thereafter, the flight requested and was given radar vectors to return to course. At 1018:42, Flight 006 requested clearance to climb. Oakland ARTCC initially cleared it to climb to FL 200, and, at 1019:17, Flight 006 told the ARTCC that "we can control the aircraft." Oakland ARTCC asked the flight if it wanted to divert to San Francisco, and, at 1019:49, Flight 006 answered "Condition normal now," and that it would continue to Los Angeles. Flight 006 was then cleared to climb to and maintain FL 350. While the airplane was climbing, the flight engineer checked his instrument panel. The body gear door open annunciator lights and the body landing gear down lights were on, indicating that the doors were open and the body landing gear were down and locked. In addition, the No. 1 hydraulic system fluid level gauge indicated empty.

Because of the landing gear indications, the captain elected to level off at FL 270 with the gear extended. (The maximum operating altitude for flight with the landing gear extended is 29,000 feet.) After checking the airplane's fuel status and fuel consumption at 27,000 feet with the gear extended, the captain decided to divert to San Francisco and instructed the first officer to inform Oakland ARTCC of their intentions. At 1035:34, Oakland ARTCC cleared Flight 006 to San Francisco via Point Reyes, California, and to maintain FL 270.

At 1038:39, Flight 006 redeclared an emergency and stated that there were injured people onboard. At 1038:54, Oakland ARTCC cleared the flight direct to San Francisco and to descend at "pilot's discretion." The descent into San Francisco was made with the autopilot engaged and it operated satisfactorily until it was disengaged at 2,500 feet while on a long final approach to runway 28L at San Francisco International Airport. The remaining landing gear and the flaps were lowered manually in accordance with prescribed checklist procedures. In addition, the engines all operated normally throughout the climb to FL 270, the cruise at FL 270, the descent, and landing.

After landing, the captain cleared the active runway. Because of the inoperative No. 1 hydraulic system which decreased his ability to steer the airplane during taxi, the captain stopped the airplane after it was clear of the active runway, the engines were shut down, and the airplane was towed to the gate.

1.2 Injuries to Persons

Injuries	Crew	Passengers	Others
Fatal	0	0	0
Serious	1*	1*	0
Minor/None	22	250	0
Total	23	251	0

*One cabin crew member received an acute back strain. On February 19, 1985, he was admitted to a hospital and was hospitalized for more than 48 hours. The passenger suffered lacerations and bone fractures on his right foot. Both injuries were classified as serious in accordance with Section 49 CFR 830.2 of the Safety Board's rules. Section 830.2 defines serious injuries, in part, as follows:

> "any injury which (1) requires hospitalization for more than 48 hours, commencing within 7 days from the date the injury was received; (2) results in a fracture of any bone [except simple fractures of fingers, toes, or nose]."

1.3 Damage to the Airplane

The airplane was damaged substantially (see section 1.12).

1.4 Other Damage

No other property damage resulted from this accident.

1.5 Personnel Information

A five-man flightcrew was on board for this flight. In addition to the primary three-man flightcrew, a relief captain and flight engineer were assigned to the flight. All flightcrew members were qualified and trained in accordance with applicable Chinese and United States regulations and prescribed China Airlines' procedures. The examination of the flightcrew's training records did not disclose anything out of the ordinary. (See appendix B.)

The primary flightcrew's captain and first officer had served in their country's air force before joining China Airlines. Neither pilot flew fighter type aircraft while in the air force and neither had done any aerobatic work since completing their air force training.

1.6 Airplane Information

The aircraft for Flight 006, a Boeing 747 SP-09, N4522V, was owned by the Wilmington Trust Company, Wilmington, Delaware, and was leased and operated by China Airlines. The airplane was powered by four Pratt & Whitney JT9D-7A engines. The airplane was maintained in accordance with applicable Chinese Civil Aviation Administration and United States Federal Aviation Administration (FAA) regulations, and also with China Airlines maintenance procedures. (See appendix C.) The airplane's weight and center of gravity locations were within applicable weight and balance limitations throughout the entire flight. At the time of the occurrence, the airplane weighed about 440,000 pounds. At this weight, the airplane's three-engine long range cruise altitude was 37,000 feet and its stall speed was about 155 KIAS.

The inspection of the airplane's flight logbook showed that the No. 4 engine had been written up on two previous flights. On February 15, 1985, the logbook indicated that the No. 4 engine lost thrust "when reducing thrust to idle at (FL) 410. Restart, resume to normal (sic) at FL 300." The logbook's corrective action taken column contained the following: the engine was inspected visually, the fuel filter was drained, and the engine vane controller was inspected and "checked Ok."

On February 18, 1985, the No. 4 engine again lost thrust, this time "when reducing thrust to idle at (FL) 430. Engine power failed to response (sic) moving thrust lever. Check F/F (fuel flow) low. Restart at (FL) 280. Resume (normal operation)." The logbook's corrective action taken column contained the following: the water drains from the mach probes manifold, the engine vane controller, the pressure hydraulic fuel filter elements, and air fuel converter were replaced; the fuel pump water filter drain was checked and found to be "normal"; and the results of a subsequent engine run up were "normal."

In addition, during the preflight inspection before the accident flight, the following malfunction was found and entered in the logbook: "No. 4 engine high stage (bleed air) valve light illuminated." The corrective action entry showed that the bleed valve was removed and replaced before the flight.

1.7 Meteorological Information

The National Weather Service's (NWS) 1000 surface weather map showed an area of low pressure over northern British Columbia and Alberta, Canada, and a large high over the northern Pacific Ocean area centered at 40° north latitude, 140° west longitude. A trough extended out of the low along the northwest Pacific coast with a cold front extending south along the coast from near Vancouver, Canada to southern Oregon and then turning west into the Pacific Ocean.

The 0400 200 millibar map (about 38,700 feet) showed a shallow trough in the westerlies extending south-southwest out of northern British Columbia into the Pacific Ocean. The centerline of the trough was about 500 nmi west of the northern California coast. A jet stream core containing wind velocities exceeding 90 knots was located on the upwind side of the trough. The wind flow in the vicinity of the accident was westerly at about 40 knots.

The 1600 200 millibar map showed that the trough had deepened and its centerline had moved just east of the northwest U.S. Pacific coast. The jet stream core was still on the upwind side of the trough with the perimeter of the 70 knot winds in the vicinity of the accident. The maximum observed wind was 160 knots about 900 nmi northwest of the accident site. Based on this pattern, the winds in the vicinity of the accident site would have been from the northwest at 70 knots.

The 1431 Geostationary Operational Environment Satellite (GOES) infrared photograph showed the location of the accident to be on the eastern edge of a cloud area which closely paralleled the surface cold front. Based on the infrared shading curve, the visible clouds appeared to be cirrus (high ice crystal clouds).

The 1100 National Weather Service sounding at Medford, Oregon showed a double tropopause with temperature minima of -67.5°C at 38,050 feet and -67.°C at 56,525 feet. The temperature at a flight altitude of 41,000 feet was -64.6°C.

Between 0752 and 1138, 11 pilot reports were received from flights transitting the area of the accident at altitudes between FL 370 and FL 410. They reported temperatures between -61°C and -64°C, and northwesterly winds ranging from 45 knots to 114 knots.

The examination of the dispatch package showed that the weather information provided to the flightcrew of Flight 006 included the forecast winds aloft enroute, a high level significant weather prognostic map, 200 and 300 millibar prognostic maps, and the TAFORs (International Terminal Forecasts) for Los Angeles, San Francisco, and Oakland.

1.8 Aids to Navigation

Not applicable.

1.9 Communications

There were no known communications malfunctions.

1.10 Aerodrome Information

San Francisco International Airport, elevation 10 feet, is located 8 miles southeast of downtown San Francisco, and is served by eight runways. Runway 28L is 10,600 feet long and 200 feet wide, and has an asphalt surface.

1.11 Flight Recorders

The airplane was equipped with a Fairchild A-100 cockpit voice recorder (CVR), Serial No. 15119. The CVR was brought to the National Transportation Safety Board's Washington, D.C. Audio Laboratory for readout. The recorder contained an excellent quality 30-minute recording; however, the recorder was allowed to run throughout the entire flight and the elapsed time between the accident and landing exceeded the recording medium's 30-minute capability. In addition, the CVR was allowed to continue recording after the airplane had landed. Since the recording tape contained no pertinent information, no transcript was prepared.

The airplane was equipped with a Lockheed Air Services Model 209E Digital Flight Data Recorder (DFDR), Serial No. 717. The recorder was removed and sent to the Safety Board's Washington, D.C. laboratory for readout. The DFDR was undamaged and in working order on arrival.

The DFDR data contained VHF radio microphone keying data. These data were correlated to the times contained on the ATC transcript of communications between Flight 006 and Oakland ARTCC to establish a real time reference for the various events contained on the DFDR readout. The timing correlation is accurate to within 1 second.

Computer Animation.--A real-time animation of a line drawing of an airplane, driven by selected flight recorder parameters, was prepared. The animation covers 6.5 minutes of the flight from 1008:53 to 1015:23, when DFDR data was lost (see section 1.11.1). The animation displays an airplane model flying over the surface of the earth (a 10-nautical mile grid), plus altitude, airspeed, heading, control wheel position, and time in digital format. It also contains an analog display of control wheel position and EPR. The parameters of pitch, roll, and derived ground track are shown via the computer generated model. The ground track was developed using the forecast winds, temperatures, and the DFDR recorded altitude, airspeed, and heading values. ATC communications on the audio are synchronized with the video display.

The airplane model is positioned in the center of the screen while the grid depicting the surface of the earth moves to show groundspeed, track, and attitude. The viewer is positioned 300 feet behind and 50 feet above the center of the model with a viewing angle equal to the magnetic heading. The DFDR data were interpolated linearly in 1/14-second intervals to produce a smooth real-time presentation. The 1/14-second interval was dictated by the limitations of the Safety Board's computer hardware.

The presentation depicts the loss of thrust from the No. 4 engine at 40,900 feet. It also shows the increasing left-wing-down control wheel offset to counteract the increasing asymmetric force resulting from the loss of thrust, until the maximum control wheel offset available to the autopilot is reached. The presentation shows that the airplane pitched down and rolled to the right. The nosedown pitch angle reached 69° and, by the time the airplane had descended to 30,000 feet, it had almost completed a 360° right roll and had pitched upward to about 11° nosedown pitch attitude. (Figures 1-7 were extracted from the computer animation.)

1.11.1 Digital Flight Data Recorder Information

Recorder Data Losses.--The examination of the DFDR readout disclosed a number of periods where data were lost. These data losses were the result of the vibration and the sustained vertical acceleration forces (Gs) exerted on the recorder during the descent. Some of these data were retrieved through the use of recovery techniques, but the accuracy of these recovered data is suspect. In addition, anomalies in the recorded altitude and airspeed values appeared early in the descent because the descent rate of the airplane had exceeded the maximum tracking capability of the airplane's digital air data computer (DADC). Specific details are discussed below.

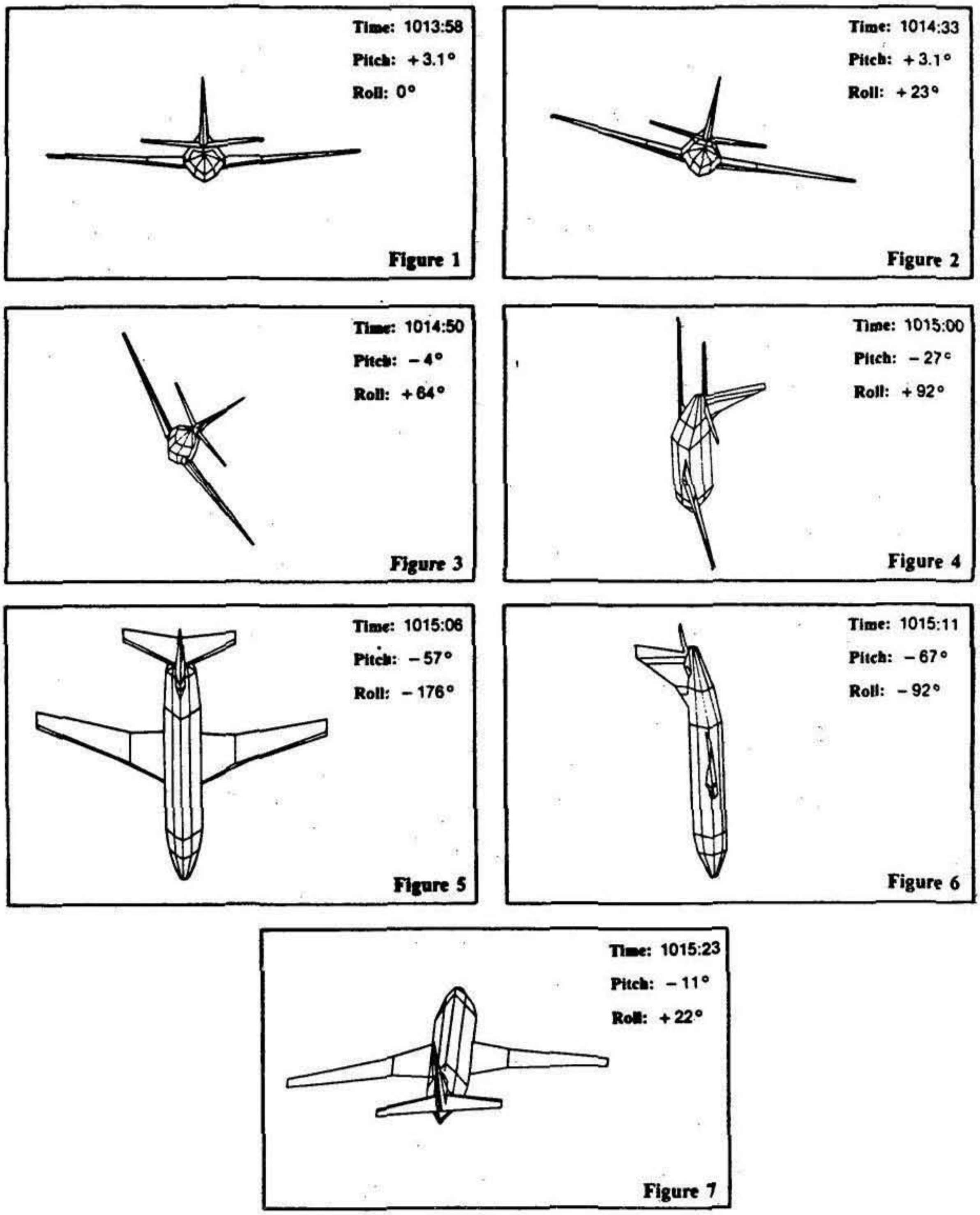
The first sustained data loss occurred at 1015:23 as the airplane was descending through 30,132 feet at 296 KIAS 7/ and the vertical acceleration values approached 5 Gs. Thereafter, invalid data was recorded for several periods during the early part of the descent.

Between 1016:08 and 1016:14, and between 1016:23 and 1017:12 during the descent, the synchro parameters for altitude (two synchros), indicated airspeed, heading, pitch, and roll displayed erroneous data, whereas the synchro parameters for the flaps, stabilizer position, control wheel position, and angle of attack were recorded correctly. The ten synchro inputs discussed above are divided into two groups: Group 1 contained the six synchros that displayed erroneous data; Group 2 contained the four synchros that displayed correct data. Power for the Group 1 synchros is routed through the standby ignition switch from the standby a.c. bus, which is normally powered by the essential AC bus. Placing the standby ignition switch at either standby ignition number 1 or number 2 will cut off power to the Group 1 synchros. The Group 2 synchros receive their power directly from the essential a.c. bus. As noted earlier, the flight engineer had placed the standby ignition switch to either the number 1 or the number 2 ignition system during the descent.

DFDR Readout Information.--At 1010:06, the DFDR data showed that the airplane was at 41,006 feet, that all four engine EPRs were about 1.4, and that the airplane was accelerating through 258 KIAS. About 1010:08, the engine pressure ratios began decreasing, but the airplane continued to accelerate until, at 1010:36, it was indicating 264 KIAS. As the EPRs continued to decrease, the airplane began to decelerate. By 1010:46, the EPRs had decreased to about 0.9, and at 1011:05, the airplane had slowed to about 255 KIAS. The wings were essentially level and the control wheel was centered. At these altitudes and at 0.84M, the EPR at idle rpm should be about 0.7 to 0.75; the windmilling EPR should be about 0.05 to 0.07 lower than the idle EPR.

At 1011:10, after the airspeed had decreased to about 251 KIAS, the EPRs on engines 1, 2, and 3 began increasing and, by about 1011:30, they had reached about 1.5 EPR. (At 41,000 feet, 0.85M, and with two air conditioning packs operating, the "max cruise" EPR limit is 1.543 EPR.) Thereafter, these three EPRs remained at about 1.5 until shortly after the start of the upset. During this period, the No. 4 engine's EPR

7/ These altitude and airspeed data were recorded in the region affected by the limited tracking capability of the DADC.



Figures 1.--Excerpts from Computer Animation.

increased from 0.9 to about 1.02 and remained fairly constant at that reading until 1012:06. Between 1012:06 and 1012:41, the No. 4 EPR increased slightly to about 1.05.

Between 1011:10 and 1012:38, the airspeed fluctuated between 248 KIAS and 253 KIAS and then stabilized at about 250 KIAS. The airplane's roll angle increased from 0.3° to about 2° left-wing-down and the control wheel began deflecting left until, at 1012:30 it stabilized at about a 7° left-wing-down deflection.

At 1012:40, the No. 4 engine's EPR began decreasing and from 1012:45 to 1013:05, the DFDR recorded EPR readings ranging from 0.83 to 0.69, but by 1013:10, the reading had increased to about 1.01 EPR. During this 30-second period, the other three engines were stabilized at essentially 1.5 EPR; the airspeed decreased from 251 KIAS to 243 KIAS, and, although the airplane remained at 40,900 feet in a 3° left-wing-down attitude, the left-wing-down control wheel deflection increased from about 7° to about 20°. With regard to engine EPR characteristics at low engine rpm, flight test data obtained during flights conducted between 39,000 and 43,000 feet demonstrate that an increase in recorded and displayed EPR values occurs at low power settings due to inlet spillage over the strut mounted compressor inlet total pressure (PT2) probe.

Between 1013:10 and 1015:06, the Nos. 1, 2, and 3 engines remained at about 1.5 EPR while the No. 4 engine remained at about 1.1 to 1.2 EPR. The airplane continued level at 40,900 feet, but the airspeed continued to decrease at a rate of about 0.25 KIAS/sec. Although the roll angle of the airplane remained fairly constant at about 2.6° to 3.5° left-wing-down, the left-wing-down deflection of the control wheel continued to increase as the indicated airspeed decreased, and, by 1013:43 the deflection had increased to 22.9°, the maximum available input from the autopilot. As the airspeed continued to decrease and with the control wheel deflected to, and remaining essentially at, the 22.9° left-wing-down deflection, the airplane began rolling slowly to the right, reaching a wings-level attitude by 1013:58 and then continuing on into a right-wing-down attitude. (See figure 1.)

By 1014:33, the airspeed had decreased to 225 KIAS. Despite the 22° left-wing-down control wheel deflection, the airplane had rolled 23° right-wing-down. (See figure 2.) The airplane's pitch attitude, which until this time had remained constant at 3.1° noseup, now decreased to 1.8° noseup and remained at that angle for about 5 to 6 seconds before returning to the original noseup attitude. During this period, the airspeed increased about 1 KIAS and then began decreasing again. The airplane continued rolling to the right at an increasing rate. In addition, the airplane had begun descending at a rate of about 1,200 feet per minute.

By 1014:50, the airplane had descended to 40,442 feet, the airspeed had decreased to 221 KIAS, and the airplane had rolled and pitched to a 64° right-wing-down and 4° nosedown. (See figure 3.) The 22.9° left-wing-down control wheel deflection had decreased to 20° and, over the next 3 to 4 seconds the control wheel returned to center. In addition, between 1013:06 and 1014:50, the heading had increased from the original 106° heading to 163°.

Between 1014:50 and 1015:23, the DFDR recorded a 10,310-foot descent to 30,132 feet. Between 1014:59 and 1015:06, as the airplane descended from 40,346 feet to 37,102 feet, the recorded data showed a right-wing-down control wheel deflection. The maximum 59° right-wing-down deflection occurred at 1015:00 and then decreased to a right-wing-down deflection which varied between 4° and 16°. At 1015:07, the recorded data showed a 57° left-wing-down control wheel deflection. During the 10,310 foot descent, the recorded data showed that the airplane's pitch angle decreased to 68° nose-down and then increased back to 11° nosedown. The airplane had rolled over on its back and continued rolling to the right through the wings-level point and to a 25° right-wing-down attitude, essentially completing a full 360° aileron roll. (See figures 4, 5, 6 and 7.) In addition, between 1015:04 and 1015:08, as the airplane was descending, the Nos. 1, 2, and 3 EPRs decreased from about 1.4 EPR to about 1.1 to 1.2 EPR and were at those values when synch was lost on the DFDR at 1015:22. At 1016:06, when synch was restored, the Nos. 1, 2, and 3 engine EPRs were still about 1.1 to 1.2 EPR and remained at those values until 1017:13.

Between 1015:23 and 1017:15, the airplane descended from 30,132 feet to 9,577 feet. During this period, except for some short 3- to 7-second intervals of accurate data, the data recorded by the DFDR were, as stated earlier, either unreliable or erroneous. For example, during the final minute of the descent, the Group 1 synchros were displaying erroneous data. At 1017:13, when the Group 1 synchros began displaying correct data, the airplane was at 9,577 feet and climbing and the airspeed was 221 KIAS. The EPRs on engines 1, 2, and 3 were about 1.23, 1.27, and 1.23, respectively, and increasing, and the thrust increase was accompanied by a 3° left rudder pedal deflection. The number 4 engine EPR was 0.9 and remained constant at that value over the next 40 seconds. While the airplane's altitude remained relatively constant, the indicated airspeed increased slowly until, at 1017:43, the airplane accelerated through 250 KIAS. At 1017:53, the No. 4 engine's EPR began increasing, and, by 1018:12, all four engine EPRs were essentially stabilized at about 1.3 EPR. At 1018:42, Flight 006 requested clearance from Oakland ARTCC to climb.

The lowest indicated airspeeds were rcorded between 1016:14 and 1016:22. During this period, speeds between 54 KIAS and 110 KIAS were recorded.

The DFDR data showed that the captain did not introduce any rudder pedal corrections to counteract the asymmetrical forces created by the loss of thrust from the No. 4 engine prior to the loss of control of the airplane.

The maximum vertical acceleration forces recorded during the descent were 4.8Gs and 5.1Gs as the airplane descended through 30,552 feet and 19,083 feet, respectively. The 5.1G peak value was recorded on a portion of the tape where data had been lost originally and subsequently recovered, but this value is consistent with the adjacent data which show an arresting of descent rate and a pull-up.

1.12 Wreckage and Impact Information

All the damage found on the airplane occurred during the descent and was caused by aerodynamic overload forces.

Wings and Engine Pylons.--The wings were bent or set permanently 2 to 3 inches upward at the wingtips; however, the set was within the manufacturer's allowable tolerances. The left outboard aileron's upper surface panel was broken and the trailing edge wedge was cracked in several places.

Wing and Body Landing Gear.--The left and right wing landing gear uplock assemblies had separated from their attachment points on the fuselage structure. The interior skin and associated ribs on the left and right wing gear inboard doors were damaged in the vicinity of their striker plates and the striker plates also were damaged.

The doors were damaged in the area where the tires are located when the gears are retracted.

The left and right body landing gear uplock hooks were found in the locked-up position, but the fasteners of their uplock support bracket assemblies had failed at the attach points to the fuselage bulkhead.

The left and right body gear actuator doors had separated, but the forward lateral beams and associated door actuators had remained attached to their respective assemblies, and there were tire marks on the sections of structure attached to the lateral beams. (Note: The uplock assemblies hold the body gear in the retracted position after gear retraction is completed. Except for the body gear tilt assembly, which is pressurized by the No. 1 hydraulic system, the body gear actuators are unpressurized. The tilt assembly is pressurized and remains pressurized so that the body gear wheel bogies can enter or leave their wheel wells without their tires striking the forward wheel well structure.)

Empennage.--The major damage to the empennage was limited to the Auxiliary Power Unit (APU) compartment, the horizontal stabilizers, and elevators. The APU had separated from its mounts and was resting on the two lower tail cone access doors. The forward side of the APU fire bulkhead appeared to be deflected forward in the area adjacent to the two lower attachment fittings and the two lower support rods had buckled. In the area of the APU, there were several punctures in an outward direction on both sides of the tail cone.

The aft pressure bulkhead was undamaged.

A large part of the left horizontal stabilizer had separated from the remainder of the stabilizer. The separated portion, which began at the outboard tip of the stabilizer, was about 10 to 11 feet long and included the entire left outboard elevator. The hydraulic lines from the No. 1 hydraulic system to the left outboard elevator actuator were severed near the actuator. (See figure 8.)

The right horizontal stabilizer incurred a similar separation. The separated portion included the entire tip of the stabilizer. However, beginning about 5 feet inboard of the tip, the separation moved directly aft to the area of the rear spar and then inboard an additional 5 to 6 feet along the forward edge of the box beam area. The separated portion of the stabilizer included the outboard three-quarters of the outboard right elevator. The hydraulic lines to the outboard elevator actuator remained intact. (See figure 8.)

Powerplants.--Except for some rotational scrubbing on the fan rotor rub strips of the Nos. 1 and 4 engines, none of the four engines were damaged during the accident. A boroscope examination of selected accessible areas of the No. 4 engine's front and rear compressors did not disclose any damaged areas.

1.13 Medical and Pathological Information

Except for the one cabin crew member admitted to a hospital after landing, medical examinations of the flight and cabin crew members were not conducted after the accident nor was toxicological testing of the flightcrew performed.

Figure 8.—Photograph of Empennage.

1.14 Fire

There was no fire.

1.15 Survival Factors

The damage to the passenger cabin was confined to several overhead luggage storage bins and two passenger seats. The seatback at seat 36E was overextended rearward and about 60° aft of upright. When it was brought up to the normal upright position, it would not lock, and fell rearward to the overextended position. The armrest between seats 36D and E was overextended about 60°. It could be raised to the normal up position, but would not go forward to the normal down position. The Safety Board could not determine whether these seats were either assigned to passengers before departure or had been occupied by passengers at the time of the upset. The airplane had 281 seats, 30 of which were not occupied.

The hinges of five storage bins were either sprung or pulled from their mounts and the stops on two bins were missing. Four overhead bins were found open but undamaged.

Two passengers and 10 flight attendants were interviewed, but not all of those interviewed could recall the events of the upset, the descent, and the recovery. Most of those who could recall said that they felt an initial period of moderate negative G forces lasting several seconds followed immediately by a period of stronger positive G forces lasting several seconds. The positive G forces decreased momentarily and was followed by a period of even stronger positive G forces lasting several minutes. Almost all of the interviewees concurred that the initial rolling motion of the airplane was to the right.

1.16 Tests and Research

1.16.1 Powerplants

Upon completion of the visual and boroscope inspections of the engines, engines No. 1, 2, and 3 were started and the airplane was taxied to San Francisco International Airport's engine run-up area for engine run-up tests. Because the direction of airport traffic would not permit the airplane to be turned into the wind, all of the engine tests were conducted in a prevailing 17-knot tailwind. The evaluation of the data obtained during the run-ups of the engines showed that they were operating within prescribed parameters.

Variable stator vane instrumentation was installed on the No. 4 engine to record the positioning of the variable stator vanes during the run-ups at the airport. The evaluation of the data obtained during the run-up of the No. 4 engine showed the following: N1 (front compressor) and N2 (rear compressor) rotor speeds were normal; at idle thrust, the variable stator vanes were open about 1° to 1.5° above the idle thrust trim point schedule limits; however, at the higher thrust conditions, the subsequent vane positions were within the scheduled trim points. In addition, at the high thrust conditions, the exhaust gas temperature (EGT) was 32°C higher than that produced by a newly refurbished engine at similar high thrust levels. These test data were sent to the manufacturer for a performance evaluation of the No. 4 engine's operational parameters.

On February 27, 1985, the No. 4 engine was removed from the airplane and installed in United Air Line's San Francisco maintenance facility's high bypass ratio turbofan engine test cell and subjected to a calibration check to obtain detailed controlled engine performance and transient operating data. The test cell data were evaluated using the manufacturer's computer generated Module Analysis Program, comparing the obtained test data to baseline data obtained from average JT9D-7A production engines. Although the results of the comparison showed that the performance levels of the No. 4 engine's gas path components were normal for an inservice engine, the transient operating data also indicated that the main fuel control scheduled fuel flow was below expected levels during engine starting; the starting times from light-off to idle were about 25 seconds longer than those of an average JT9D-7A production engine. During engine accelerations above idle, the main fuel control scheduled a fuel flow that was about 200 pounds per hour (pph) toward the lean direction or about 200 pph below expected levels. The engine deceleration time was 0.25 seconds below the minimum acceptable 1.5 seconds and the ground idle speed was about 0.4 percent below the engine's nominal idle trim. In addition, the temperatures supplied to the main fuel control's fuel flow schedule were about 35° F higher than the nominal input values.

The main fuel control was disassembled to determine the source of the variations from the fuel schedule. Evidence of wear was observed on the throttle valve trimmer knife edge and the mating groove of the multiplying lever. Photographic magnification of the wear areas showed that each of these components was worn about 0.002 inch or a total wear of 0.004 inch. A loss of height (wear) between these two components would have contributed to the change in the main fuel control schedule.

In conclusion, a computer simulation of the engine performance capabilities was conducted using the data obtained during the engine testing and the estimated operating conditions of the airplane at the time of the accident. The simulation showed that if the total estimated air conditioning system bleed air load, coupled with the main fuel control's schedule deviations, were imposed on the engine, the engine would fail to accelerate or would "hang" at about 76 percent (6,000 rpm) N2 rotor speed. This situation would result in a condition described as "bleed load hogging." During normal engine operation, each engine will supply a proportionate amount of bleed air to the airplane's air conditioning system. If an individual engine remains at or near idle thrust and the remaining engines are operating at higher thrust levels, the engine at or near idle will assume a disproportionate amount of the bleed air load. This bleed load hogging condition raises the engine's "required to run line" and decreases the acceleration rate of the engine. The "required to run line" defines the performance level of an engine in terms of the amount of fuel required to produce a given rpm.

1.16.2 Human Performance Information

The Safety Board examined the relevant operational factors known to affect crew performance. These factors included flightcrew training, flightcrew in-flight duty procedures, and certain behavioral factors which, based on the facts and circumstances, might be relevant to the sequence of events.

Because of the scheduled duration of the flight, 11 hours, an augmented flightcrew was on board. In addition to the three primary flightcrew, an additional fully qualified captain and flight engineer were on board. All five crew members were interviewed by the Human Performance Group concerning their duties, training, and rest periods before and during the flight. (See appendix B.)

The captain had spent 5 days in Jeddah, Saudi Arabia, before returning to Taipei on February 14, 1985; Taipei time is 5 hours ahead of Jeddah time. He was off duty on February 15; on February 16, he flew a 2 hour 30 minute flight to Tokyo, Japan, returning to Taipei (a 3-hour flight) on February 17. According to the captain, during the nights of February 14 through February 17, he went to sleep between 2100 to 2200 Taipei time and awoke about 0700 to 0800. On February 18, he flew a round trip to Nagoya, Japan, and was off duty 15 hours 20 minutes before reporting for duty on February 19.

Flight 006 departed Taipei at 1622 local time and had been airborne about 9 hours 46 minutes when the accident occurred (0214 Taipei time). At the time of the accident, the three primary flightcrew members were on duty. They had been on duty during the takeoff, climb, and initial part of the flight. Thereafter, they each went off duty at intervals ranging from 1 1/2 to 4 hours after takeoff and were replaced by the augmentee flightcrew members, with the captain occupying the first officer's seat during a portion of this period.

The captain was off duty 5 hours during the flight and returned to duty about 2 hours before the accident. During his rest period, the captain slept about 2 hours in the bunk located in the rear of the cockpit. The first officer was off duty about 3 hours during the flight and returned to duty about 3 hours before the accident. The flight engineer was off duty about 5 hours and returned to duty about 2 hours before the accident. The first officer's and flight engineer's activities during their rest periods were not established.

<u>China Airlines Training and Flightcrew Procedures.</u>--China Airlines conducts its own Boeing 747 training using its Phase II simulator and a curriculum developed largely by Boeing.

Although captains and first officers of China Airlines generally fly alternating legs on all airplane types, company policy requires that a captain log 1,000 hours as captain on a particular type airplane before he may permit his first officer to land and take off. Thus, on the Boeing 747, a first officer may only take off and land if the captain assigned to his flight has logged 1,000 hours as captain on the Boeing 747. To compensate for this, the first officers are given additional monthly simulator training to maintain proficiency.

According to China Airlines' chief of flight training and deputy director of flight operations, their first officers are capable of flying the Boeing 747 in any emergency. The China Airlines' Boeing 747 SP Airplane Operating Manual (AOM) Emergency Procedures Section states, in part, that "The captain will take necessary action to establish and/or maintain control of the airplane and call for the appropriate checklist." Thus, according to the flight training chief and operations director, in the event of an unscheduled loss of engine thrust, abnormal engine response to throttle movements, or failure of the engine to respond to throttle inputs, the captain, while primarily directing his attention to flying the airplane, could have directed the first officer and flight engineer to deal with the tasks involved with either restoring full engine performance or shutting down and restarting the engine.

Behavioral Factors: Automation.--The automatic flight systems of the Boeing 747 SP were such that the airplane could be programmed for and was capable of fully automatic flight throughout the entire route. Once the airplane was so programmed, all that was required of the flightcrew was to monitor the progress of the airplane and from time to time update the information required by the airplane's computers. Thus, the flightcrew had been relegated to the role of monitors and had been serving in this role for almost the entire flight until the autopilot was disconnected.

As computers have been added, the pilot's physical workload, as far as physically handling the airplane, has been reduced and, during some phases, eliminated. One researcher has stated that with the addition of computers to the cockpit, the pilot's job is changing from one of manually flying the aircraft to one of supervising computers which are doing navigation, guidance, and energy management calculations as well as automatically flying the aircraft." 8/ The increased automation has not necessarily reduced pilot workload, however, but has shifted it to monitoring tasks which the pilot formerly had to perform, and there is evidence, from both research and accident statistics, that people make poor monitors. For example:

1. A laboratory study to compare failure detection performance found that the performance by participants who were actively controlling a dynamic system "was faster and more accurate" than the performance of those who were monitoring an autopilot that controlled the system. These results were attributed to the fact that in the manual mode, the participants remained in the "control loop" and benefited from the additional sensory cues derived from "hands on" interaction with the system 9/. These findings agreed with a research study by L.R. Young. 10/

8/ Palmer, E., Model for Interrupted Monitoring of a Stochastic Process, NAS TM-78, 453, 1977, p. 1.

9/ Kessel, C. and Wickens, C.D., The Internal Model: A Study of the Relative Contribution of Proprioception and Visual Information to Failure Detection in Dynamic Systems. NASA CP-2060, 1978, pp. 85-86.

10/ Young, L.R., On Adaptive Manual Control. IEEE Transactions on Man-Machine Systems, Vol. MMS-10, 1969, pp. 292-331.

2. In the Eastern Airlines L-1011 crash into the Florida Everglades, 11/ the flightcrew was distracted by a malfunctioning landing gear indicator light and failed to monitor the autopilot which was flying the airplane. The autopilot was accidentally disengaged from the altitude hold mode and the airplane gradually descended into the ground. The Safety Board concluded that the probable cause of the accident was the flightcrew's failure to monitor the flight instruments and to detect the unexpected descent "soon enough to prevent impact with the ground. Preoccupation with the nose landing gear position indicating system distracted the crew's attention from the instruments and allowed the descent to go unnoticed."

3. In 1979, the flightcrew of an Aeromexico DC-10 stalled the airplane while climbing to cruise altitude over Luxembourg. The crew either intentionally or inadvertently programmed the autopilot for the vertical speed mode rather than the procedurally directed airspeed or Mach command mode. The airplane maintained the programmed climb rate throughout the climb, but at the sacrifice of airspeed. As the climb continued, the engines reached their thrust limit, the thrust available became insufficient to sustain flying speed for that climb rate, and the airplane entered stall buffet. The flightcrew misidentified the intensifying buffet as an abnormal vibration in the No. 3 engine, reduced its thrust, and then shut it down. The airplane stalled, rolled to the right, and the recovery maneuver was executed successfully after an altitude loss of about 11,000 feet. The Safety Board found that "the flightcrew was distracted or inattentive to the pitch attitude and airspeed changes as the airplane approached the stall." 12/

Research also indicates that the excursion from a stabilized condition might be exaggerated even after a system anomaly is detected, because of the period required for a pilot to transition from system monitor mode to system controller. Time is needed to "ascertain the current status of the airplane and assess the situation," 13/ before the pilot can reenter the control loop and take corrective action.

In addition, accident investigations have also indicated a reluctance on the part of the flightcrews to disconnect an automated flight system and take manual control of the airplane even though the automated system in question may be operating outside of system limitations or will not accept or maintain programmed inputs. In cases involving two runway overruns after landing, the flightcrews continued to use the autothrottle speed control systems (ATSC) during the approaches even though the indicated airspeeds provided by the ATSCs were well above the calculated approach speeds that the flightcrews had inserted into the systems. In one accident, the Safety Board found that one of the causal factors was the captain's "decision to accept and maintain an excessive airspeed derived from the autothrottle speed control system during the landing approach

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11/ Aircraft Accident Report: Eastern Airlines L-1011, Miami, Florida, December 29, 1972 (NTSB-ARR-73-14).

12/ Aircraft Incident Report: Aeromexico DC-10-30, XA-DUH, Over Luxembourg, Europe, November 11, 1979 (NTSB-AAR 80-10)

13/ Boehm-Davis, D.A., Curry, R.E., Wiener, E.L., and Harrison R.L., Human Factors of Flight-Deck Automation-NASA/Industry Workshop, NASA TM-81260, January 1981, p. 6.

which caused the airplane to land about 2,800 feet beyond the runway's displaced threshold." 14/. In the other accident, the Safety Board found that one of the causal factors of the accident was the "over reliance on the autothrottle speed control system which has a history of recent malfunctions." 15/

As a result of that investigation, the Safety Board issued Safety Recommendation A-84-123, on November 15, 1984, urging the FAA to:

> Apply the findings of behavioral research programs and accident/incident investigations regarding degradation of pilot performance as a result of automation to modify pilot training programs and flight procedures so as to take full advantage of the safety benefits of automation technology.

The Safety Board has classified the FAA's response to this recommendation as "Open--Acceptable Action," pending completion of the FAA's actions on this issue.

Behavioral Factors: Monotony and Fatigue

Research has also been conducted to examine the effects of prolonged monotony and boredom on human performance. O'Hanlan, in a review of the literature, noted:

> A decrement in efficiency has also been found in monotonous tasks requiring little or no motor output, but instead continuous attention, perceptual discrimination and decision making. 16/

Smith, in a review similar to O'Hanlan's but based on somewhat different literature reached similar conclusions. He:

> . . .postulated that vigilance (or monitoring) tasks are always monotonous rather than interesting because they demand few if any "mental acts" and because they are prolonged and repetitive. 17/

O'Hanlan concluded that:

> . . .there is reason to believe that monotonous sensory stimulation depresses the perceptual and cognitive functions of the cerebral cortex. This could account for the performance failures by individuals in monotonous tasks. . . 16/

14/ Aircraft Accident Report: World Airways, Inc., DC-10-30CF, Boston-Logan International Airport, Boston, Massachusetts, January 23, 1982 (NTSB-AAR-85-06, supersedes NTSB-AAR 82-15).

15/ Aircraft Accident Report: Scandinavian Airlines System DC-10-30, John F. Kennedy International Airport, Jamaica, New York, February 28, 1984 (NTSB-AAR-84-15).

16/ O'Hanlan, J.F. Boredom: Practical consequences and a theory. Acta Psychologica, 1981, 49, 5382.

17/ Smith, R.P. Boredom: A Review. Human Factors, 1981, 23, 329-340.

Related to the above is a considerable body of research 18/ and 19/ which outlines the cyclical nature of many of the physiological processes in humans, including sleep-wake cycles, urinary excretion, and body temperature. These cycles, which are collectively known as circadian rhythms for their daily periodicity, exert a strong but often suble influence on human performance capabilities. Disturbance of these circadian rhythms occurs among shiftworkers, for example, who must work during the daytime on some days and at night on others, in a irregular manner. In addition, jet travelers flying east-west or transmeridian, feel the effects since they often arrive at their destination at a local time that is several hours different than the one their circadian rhythms are maintaining. As a result, researchers have noted 20/ that:

> ...a single transmeridian flight can alter the structure of sleep in addition to the length of sleep...

This can produce fatigue in addition to the fatigue normally associated with extended waking periods experienced by the transmeridian traveler.

*1.17 Other Information

18/ Aschoff, J. Circadian rhythms in man, Science, 1965, 148, 1427-1432.

19/ Siegel, P.V., Gerathewohl, S.J., & Mohler, S.R. Time-zone effects. Science, 1969, 164, 1249-1255.

20/ Graeber, R.C., Foushee, H.C., & Lauber, J.K. Dimensions of flight crew performance decrements: Methodological implications for field research. In H.M. Wegman (Ed.) Breakdown in human adaptation to stress: Towards a multidisciplinary approach, 1984: Boston, Martinus Nijhoff.

**ICAO Note.*— Section 1.17 was not reproduced.

2. ANALYSIS

The flightcrew members of Flight 006 were certificated properly and were qualified for the flight. There was no evidence that their performance was affected by medical problems. Although there were writeups relating to the loss of thrust on the No. 4 engine on the two previous flights, there was no evidence of any preexisting maintenance discrepancies that could have contributed to the accident. The facts showed that the airplane had been maintained in accordance with all applicable regulations and company requirements.

Based upon the winds and temperatures reported in the area of the accident, Flight 006 was flying in the polar jet stream just west of the centerline of a trough on the leading edge of a jet stream maxima, and between a divided tropopause. Within an atmospheric structure like this, there would have been strong horizontal and vertical wind shears and possible clear air turbulence. Based on the consistency of the temperatures reported by other airplanes operating in the area, it is doubtful that there were significant temperature variations. Since the flight encountered clear air turbulence of sufficient magnitude to require the captain to turn the "fasten seatbelt" light on, the Safety Board concludes that the airspeed variations requiring the throttle adjustments before the accident were caused by wind shear associated with the turbulence.

The flightcrew's statements about the ADIs failing were not substantiated by the facts. It is most likely that the flightcrew became spatially disoriented during the upset. They were unable to believe the information displayed on the ADIs, did not recognize the unusual attitude of the airplane, and were unable to take the correct action to recover the airplane until it began to emerge from the clouds.

Although the captain said that the airplane exceeded Vmo twice and also decelerated below 100 KIAS during the dive, all three crew members said that they did not hear the overspeed warning and that the stall warning stickshaker did not activate. Examination of the reliable recorded airspeed data points showed that the Vmo limitation was not exceeded during the descent. However, the recorder data does show airspeeds at or below 100 KIAS. The Safety Board cannot explain why the stall warning stickshaker did not activate, or if it did activate, why it was not felt or heard by the flightcrew.

The Safety Board's investigation and analysis concentrated primarily on two major areas. First, the investigation sought to identify the cause of the loss of thrust on the No. 4 engine, and thereafter to assess whether the actions taken by the flightcrew to cope with the malfunction were reasonable and proper. Second, the investigation sought to determine why the flightcrew was unable to maintain control of the airplane after the loss of thrust on the No. 4 engine.

2.1 The Engine Failure

About 1010:46, the PMS, in response to the increased airspeed caused by the wind shear, had decreased the EPRs on all four engines to 0.9 EPR. Then, about 1011:10, the PMS, in response to the now reduced airspeed, began to advance the four throttles to restore the airplane to the commanded 0.85M. The investigation of the No. 4 engine and its components showed that it had experienced a lean shift of the acceleration schedule resulting in a reduction in the fuel flow available for engine acceleration. A reduction of this type reduces the rate at which the engine would accelerate from flight idle. The DFDR data showed that all four engines started to accelerate; however, the data also showed that the No. 4 engine accelerated at a slower rate than the others. As engines Nos. 1, 2, and 3 accelerated, their respective bleed air controllers closed their 15th stage or high stage bleed air valves. Since the No. 4 engine accelerated slower than the other engines, it did not achieve high enough power for its bleed air controller to close the high stage bleed valve at the same time the high stage bleed air valves were closed on the other engines, and the No. 4 engine, at high altitude, probably assumed most of the air conditioning air bleed load. The additional fuel demand imposed by the "bleed load hogging," in combination with the reduced fuel flow available because of the control lean shift, caused the No. 4 engine to fail to accelerate and to "hang" at slightly above 1.0 EPR.

The flight engineer stated that he moved the No. 4 throttle to idle and then advanced it slowly, trying to restore the engine to normal operation. However, the procedure for restoring a "hung" engine to normal operation also required the flight engineer to close the No. 4 engine's bleed air valve (see appendix D), and this he did not do. Closing the bleed air valve shuts the high stage bleed air valve and reduces the engine's bleed air load supply requirements. However, given the altitude at which the airplane was flying, and the fact that the flight engineers on two previous flights were unable to restore the engine to power under similar circumstances, the Board cannot state that the flight engineer would have been able to restore the engine to normal operation even had he closed the bleed air valve. Since the DFDR showed that the No. 4 engine did not accelerate with the other engines and remained at about 1.0 EPR until it fell below that EPR value at 1012:42, the Safety Board concludes that the No. 4 engine had not flamed out initially, but had "hung."

At some indeterminate time thereafter, the flight engineer decided that the No. 4 engine had flamed out and informed the captain. Between 1012:42 and 1013:04, the No. 4 engine EPR dropped from 1.0 to about 0.7 EPR. By about 1013:09, the No. 4 engine EPR had returned to about 1.0. Based on these data, and the fact that the flight engineer said that he had not moved the engine start lever to cutoff, the Safety Board concludes that engine No. 4 did flame out about 1012:42 and began to decelerate toward windmilling rpm; the subsequent increase in the EPR was caused by inlet spillage from the windmilling engine over the PT2 pressure probe on the strut. The restart attempt was unsuccessful because the attempt was made well above the altitude limits of the inflight airstart envelope.

About the time that the airplane was entering an unusual attitude, but before the G forces rendered him immobile, the flight engineer stated that the other three engines had lost thrust. He advanced the throttles, but said that the engines did not respond. He then placed the standby ignition switch on, and sometime after that he was pinned to the aisle stand by G forces.

The Safety Board believes that the Nos. 1, 2, and 3 engines had not flamed out and that the low engine parameters observed by the flight engineer resulted from the throttles being at or near idle. Advancing the throttles at this point would have produced an engine accleration which was much slower than would be observed at sea level because the acceleration fuel schedules are biased by total air temperature. Based on the flight engineer's description, he must have observed the Nos. 1, 2, and 3 engines and manipulated their throttles somewhere above 30,000 feet; the cold temperatures existing at these altitudes will result in lower acceleration fuel flow available and a lower acceleration rate. In addition, the airplane's changing attitudes, the maneuvers it was undergoing, and the resultant high G forces may have compromised the engineer's ability to conduct a proper and thorough scan of the applicable engine instruments.

The DFDR data indicates that the flight engineer's recollection of the time at which he placed the engine ignition to standby was not accurate. The flight engineer stated he did this right after he had decided that engines Nos. 1, 2, and 3 had lost thrust. Thereafter, he said, he was rendered immobile by G forces and was forced down against the aisle stand. At 10,000 feet and about the time that the captain said that he saw the horizon outside the airplane, he said that he again "hit the standby ignition; Nos. 1, 2, 3, started, No. 4 did not." The DFDR data showed that the Group 1 DFDR synchros were lost for about a 5-second period beginning about 1016:08, indicating that standby ignition had been selected at that time. From 1016:14 to 1016:22, the Group 1 synchros recorded accurate data, indicating that standby ignition was off. During that 8-second period, the airplane descended from 14,541 feet to 13,950 feet and the airspeed increased from 87 KIAS to 110 KIAS. From 1016:23 to 1017:12, the Group 1 synchros were lost again, indicating that standby ignition had been reselected again. During this period, at about 1016:41, the Nos. 1, 2, and 3 EPRs began increasing. At 1017:13, when the Group 1 synchros were restored, the airplane was at 9,577 feet, at 221 KIAS, and in fairly stable flight. The EPRs on engines Nos. 1, 2, and 3 had increased from about 1.01 to 1.23 and were continuing to increase. Since the captain was decreasing the descent rate during this time and was allowing the airplane to accelerate smoothly, the Safety Board believes that it was highly unlikely that the airplane ever achieved the necessary 250 KIAS to permit a successful airstart on engines Nos. 1, 2, and 3 and that, in fact, they had not flamed out.

The contention that engines Nos. 1, 2 and 3, did not flame out is further supported by the following:

1. Cabin pressurization did not drop to the point that passenger oxygen masks were deployed.

2. The No. 4 generator breaker had opened when the No. 4 engine was shut down. Had the other three engines flamed out, their three generators would have tripped and the essential a.c. bus would have lost power. Had that happened, the DFDR would have ceased operating, and, in addition, instrument warning flags would have appeared. Neither of these events occurred.

3. The engine low oil pressure warning lights did not illuminate.

Based on these data, the Safety Board concludes that the Nos. 1, 2, and 3 engines did not flame out and continued to operate throughout the loss of control, descent, and recovery.

While there can be little doubt that the loss of thrust on the No. 4 engine was the precipitating factor of the accident sequence, the loss of one engine, albeit an outboard engine, during high altitude cruise should not cause an experienced flightcrew to lose control of their airplane. Indeed, the Airline Operating Manual does not even classify this mishap as an emergency procedure. Therefore, the Safety Board directed its attention to the reasons why the flightcrew was unable to maintain control of the airplane after the loss of thrust on the No. 4 engine.

2.2 The Flightcrew

Although the facts developed during the investigation showed conclusively that the accident occurred because the captain failed to maintain control of the airplane after the loss of thrust on the No.4 engine, the Safety Board also sought to determine the reasons that may have led to the captain's inability or failure to employ the procedures that would have prevented this from happening. Therefore, in its analysis, the Safety Board evaluated data contained in past reports of similar accidents, as well as psychological literature discussing the factors that contribute to breakdowns in decision making and monitoring capability. These areas included boredom, monotonous environmental conditions, fatigue due to circadian desynchronosis, and over-reliance on automated flight systems. In addition, the manner in which the first officer and flight engineer performed during the loss of control sequence was also evaluated in relation to the above areas.

Although the first officer was capable of either flying the airplane or assisting the flight engineer in his analysis of the loss of thrust on the No. 4 engine, the captain did not task him specifially with either chore. During this period, the additional task levied on the first officer was to obtain clearance from Oakland ARTCC to descend, and the captain did not direct the first officer to obtain an emergency descent clearance. The facts showed that the first officer performed his communications duties in a timely manner; that he had warned the captain of the decreasing airspeed and the increasing right bank; that after the No. 4 engine flamed out he had, without informing the captain, instructed the relief flight engineer to come forward and help the flight engineer restart the No. 4 engine; and that he came to the captain's assistance on the flight controls without being instructed to do so. Although the first officer was subject to fatigue, boredom, and the same monotonous environment as the rest of the crew, and although he had less off-duty time during the flight than the captain and flight engineer, he seemed to have performed his assigned duties and overall monitoring tasks in a timely manner. Given these factors, the Safety Board cannot state with any confidence that any of the psychological factors that could have reduced his capability to perform affected his actions during the accident sequence. The facts, limited as they are, indicate that his performance was unaffected by these factors.

With regard to the captain and flight engineer, both men were performing in a time spectrum that was later than their typical sleep periods. Although both men had taken a 5-hour rest during the flight, the quality of their rest during this period cannot be equated to that which would have been achieved by sleep either at home or in a hotel. Their duty tasks consisted of routine monitoring of the performance of the airplane's automated flight systems, a task that is repetitive and monotonous and capable of producing a state of boredom. The existence of these conditions required the Safety Board to examine the possibility that they might have influenced and derogated the manner in which the flight engineer and captain performed during the emergency.

The flight engineer's performance before, during, and after the loss of control disclosed actions that were correct and timely and other actions that deviated from the required checklist procedure or that demonstrated that he had been unable to analyze correctly the portrayal of the airplane's engine instruments. During the 1 minute 20 second period between the inception of the "hung" engine and the flameout, the flight engineer informed the captain of the status of the engine, moved the throttle aft, then moved it forward to align with the other throttles and awaited the results of the procedure. Since the procedure requires the throttle to be moved slowly and also incorporates a time to interval to wait and evaluate the engine response, the 1 minute and 20 seconds required to accomplish the task, evaluate the engine response with the captain, and then decide that the engine had either flamed out or had flamed out during his efforts to restore the engine to normal performance were correct and appear to be timely. The facts showed that the flight engineer did not review the alternate operations procedure for this malfunction before trying to restore the engine; however, the AOM states that this procedure may be performed "by recall or references," and also that the AOM may be reviewed before accomplishing the procedure. As a result, the flight engineer did not recall that he was required to close the bleed air valve before manipulating the throttle.

After the flight engineer told the captain that the No. 4 engine had flamed out, the captain ordered him to restart the engine. The flight engineer, without referring to the checklist, placed the second ignition system of the No. 4 engine to the "flight start" position, thus providing continuous ignition from both igniters to the engine's chambers. This action was required by the applicable checklist procedure.

During the descent, the flight engineer had concluded erroneously that the other three engines had flamed out. Several factors led to this misdiagnosis. Shortly after the upset, engines Nos. 1, 2, and 3 were reduced to flight idle thrust. The flight engineer did not move these throttles; thus, when he saw the engine instruments during the dive, the EPRs on engines Nos. 1, 2, and 3 had decreased from their cruise thrust of about 1.5 EPR to flight idle and were nearly aligned with that of the No. 4 engine, which he knew had flamed out. The failure of these three engines to respond to throttle movements would also tend to indicate that the Nos. 1, 2, and 3 engines had flamed out. Since he had observed that the No. 4 generator was off the line as a result of the flameout of the No. 4 engine, the fact that the airplane still had a.c. electrical power should have alerted him to the possibility that the remaining engines had not flamed out, certainly not all of the remaining engines. Perhaps the flight engineer should have checked the generator panel; however, when the upset occurred, he was facing forward and trying to evaluate the thrust readings. The electrical panel would have been 2 to 3 feet to the right and slightly aft of him. During the dive, the flight engineer's face was pressed into the center aisle stand by the "G" forces; thus, any attempt to see the electrical panel would have been somewhat difficult. However, having reached this erroneous conclusion, his next action, albeit based on the erroneous conclusion, was timely and was required by the Multiple Engine Shutdown/Failure emergency checklist; he turned on the standby ignition switch.

The evaluation of the flight engineer's performance shows that for the most part, his actions were timely and correct; however, he forgot to close the engine bleed valve switch and he was not able to evaluate correctly the operational status of engines Nos. 1, 2, and 3. These deviations from checklist procedures and the inability to evaluate the status of engines Nos. 1, 2, and 3 correctly could be attributable to any one, or all, of the following factors: a lack of knowledge of the airplane systems and procedures; the traumatic effect of the upset and subsequent descent on the flight engineer's ability to scan the center and flight engineer's instrument panels closely and accurately; and the deleterious effects of fatigue resulting from the combination of monotony and boredom, circadian desynchronis, which affected the flight engineer's ability to monitor his instruments properly, to obtain all the available data in a timely manner, and to analyze these data accurately. Based on the flight engineer's performance of his duties, the Safety Board can find little if any evidence to support a conclusion that the effects of monotony, boredom, and fatigue impaired the flight engineer's performance of his duties. The Safety Board concluded that a preponderance of the evidence showed that the deviations and omissions noted above resulted from either a lack of knowledge of the airplane systems and procedures, the traumatic effects of the upset and subsequent descent on the flight engineer's ability to scan his instrument panels, or a combination of these two factors.

In the event of an abnormal flight condition, company policy and the AOM dictated that the captain assume control of the airplane and direct the other crew members to deal with the abnormal condition. Since the captain was at the controls when the flight engineer told him that the No. 4 engine did not accelerate, there was no need for him to take any further action other than to monitor the flight engineer's attempts to analyze the engine's performance and restore it to normal operation. He did not disengage the autopilot since it relegated the tasks involved with flying the airplane to merely monitoring the autopilot's performance. Had he disengaged the autopilot, as recommended in his training, he would have been required to perform the physical, more difficult, and more time and attention consuming tasks involved with flying the airplane manually.

The effects of the asymmetrical thrust condition began to assert themselves at about 1011:10, and the No. 4 engine flamed out about 1012:42. Based on the decrease in pitch attitude and the subsequent momentary airspeed increase, the Safety Board concludes that the the PMS was disengaged about 1014:30. Based on the initial movements of the control wheel from its 22.9° left-wing-down position, the Safety Board also concludes that the autopilot was not disengaged until 1014:50. During the 3 minute 40 second period of deceleration, the statements of the captain and flight engineer showed that the captain was totally cognizant of the engine situation, and thereafter, his attention appeared to focus almost exclusively on the airplane's decreasing airspeed. According to the captain, he had disengaged the autopilot in order to lower the nose of the airplane faster and recover airspeed. Although he said that he was aware that the airplane had entered a right bank, he was apparently not aware of the magnitude of the right-wing-down attitude.

The Safety Board concludes that one of the causal factors of the accident was the captain's reliance on the autopilot while the airplane was decelerating. During this 3 minute 40 second period, the captain allowed himself to remain removed from the "control loop" by leaving the autopilot engaged. As a result, he was not aware of the increasing control inputs required to maintain level flight. Had the captain placed himself in a "hands on" relationship with the airplane by disconnecting the autopilot at the onset of the engine problem, he probably would have been more alert to the increasing asymmetrical forces being exerted on the airplane since he would have been required to make the necessary control inputs to maintain level flight. Since he had no physical relationship with the airplane flight controls, the only cues available to him to monitor the airplane's attitude and performance were the visual cues available from either the airplane instruments or the outside horizon since the airplane was flying above the clouds. However, even under conditions of visual flight, the flight instruments remain the primary tools at high altitudes for maintaining level, stabilized flight in large airplanes. The captain's statement corroborated the fact that he was relying on these instruments for that purpose. Under these conditions, therefore, the primary instrument for attitude control was the attitude director indicator, which may not have concerned the captain initially since it depicted either a wings-level attitude or a very slight left-wing-down bank. With regard to heading, over the period between 1011:09 to about 1014:00, the heading increased about 4°, a change so slight as to be almost imperceptible. Thus, except for airspeed, which concerned the captain greatly, the only thing in the cockpit that would have depicted the worsening control situation was the control wheel's increasing left-wing-down deflection. However, this was an area which was not included in the captain's regular instrument scan pattern, and since he was not "hands on," he was not aware of the deflection.

During the latter part of this period, the captain's statement indicated that his attention seemed to be directed almost solely to the airspeed indicator as he tried to arrest the airspeed decrease. Thus, when he failed to arrest the decrease by disengaging the PMS and lowering the airplane's nose by rotating the pitch control wheel on the autopilot manual control module, he disconnected the autopilot.

As noted earlier, an excursion from a stabilized condition might be exaggerated during the transfer from system monitor mode to system controller because time is needed to ascertain the status of the airplane and assess the situation before the pilot can reenter the control loop and take corrective action. When the autopilot was disengaged, the airplane's excursion from the stabilized condition was well advanced and at the point where immediate and proper corrective action was required if the situation was to be remedied safely. The captain was not only unable to assess the situation properly, he was confused by it; therefore, he was unable to take the necessary action to correct the situation. The DFDR data indicated that his actions most probably aggravated the situation. The Safety Board concludes that the captain became spatially disoriented at the onset of the upset and was unable to reorient himself until the airplane began to emerge from the clouds. The fact that the first officer was unable to help the captain reorient himself during the descent showed that he also became disoriented during the upset and descent.

The Safety Board further notes that the captain did not, as was recommended during his training and in his training manual, disengage the autopilot when the No. 4 engine initially "hung." Thereafter, he relied on the autopilot to maintain the airplane in straight and level flight during the deceleration, and he did not apply left rudder trim to level the control wheel before disengaging the autopilot. Since the decreasing airspeed was initially and readily apparent and would, if allowed to continue unchecked at FL 410, seriously menace the safety of his airplane, the captain's continuing preoccupation with airspeed control was understandable. However, the captain was an experienced multiengine and Boeing 747 pilot and he also should have known how the loss of thrust from an outboard engine would affect an airplane's controllability, especially when it is coupled with decreasing airspeed. Given his Boeing 747 experience, the captain should have also known that the autopilot's lateral control authority did not include the rudder and that the effects of the thrust loss could only be counteracted by introducing a left-wing-down roll, an action which would also introduce a side slip, increase drag, and aggravate the airspeed decrease. Given these circumstances, the Safety Board explored the reasons why the captain was not alert to this condition and why he was not monitoring his attitude direction indicator more closely during this phase of the operation. Had he done so, he would have noted the airplane was rolling right-wing-down, that the autopilot could no longer maintain the airplane's heading and roll attitude, and that additional control inputs were required, i.e., rudder or rudder trim. The DFDR readout showed that after the No. 4 engine had "hung," the airplane accelerated to about 250 KIAS and stabilized at that airspeed for about 1 minute 30 seconds. During this period, the autopilot maintained the airplane at a relatively wings-level attitude with left-wing-down control wheel deflections of about 6° to 10°. The full effects of asymmetrical thrust were not felt until after the No. 4 engine flamed out. Thereafter, the airplane began to decelerate, its rate of deceleration began to increase, and the captain's statement showed that his attention began to focus almost exclusively on the airplane's airspeed. When the captain disconnected the PMS from the autopilot, the airplane was rolling through the 20° right-wing-down attitude and the evidence showed that the captain did not observe the airplane's roll attitude. After disengaging the PMS and inserting a nose-down control correction into the autopilot, the captain continued to monitor the airspeed indicator to observe the results of the nose-down control correction. During this period, the airplane continued to roll to the right and past the 45° right-wing-down attitude. Although the ADI is to the right of and abuts on the airspeed indicator, the captain never noticed the right-wing-down ADI indications until he disconnected the autopilot. The evidence showed that, starting just before he disconnected the PMS, the captain was distracted by the decreasing airspeed. With the continuing decrease, the captain's distraction with the airspeed increased to the point where his instrument scan pattern broke down and his visual attention became fixed on the airspeed indicator. The ADI went unobserved. The Safety Board can only conclude that the captain was distracted first by the evaluation of the engine malfunction and second by his attempts to arrest the decreasing airspeed, and that, because of these distractions, he was unable to assess properly and promptly the approaching loss of airplane control. The Safety Board also concludes that the captain over-relied on the autopilot and that this was also causal to the accident since the autopilot effectively masked the approaching onset of the loss of control of the airplane.

Although the Safety Board has cited distraction and over-reliance on the autopilot as causal factors, it also notes that the airplane had been airborne about 10 hours, that it had traversed several time zones, and that the upset occurred about 0214 Taiwan local time, or about four to five hours after the captain had been accustomed to going to sleep. Thus, his ability to obtain, assimilate, and analyze all the data presented to him could have been impaired by the effects of monotony, boredom, and fatigue. However, an analysis of the captain's performance does not support a conclusion that the his performance was impaired by these factors. The facts and circumstances showed that the captain was alert to the situation as it developed. The data also showed that the captain had five hours rest during the flight, that he had slept two hours during this period, and that he had been at his duty station about 3 hours when the upset occurred. The Safety Board concluded that the preponderance of the evidence showed that the deviations and omissions from prescribed airplane procedures noted in the captain's performance resulted from the causal factors cited earlier, i.e., distraction and over-reliance on the autopilot.

In conclusion, the Safety Board believes that the loss of thrust on the No. 4 engine was the precipitating factor in the accident; however, we do not believe that it should be considered a contributory factor. Except on takeoff, at, or shortly after critical engine failure speed, an engine loss does not require an emergency procedure wherein immediate and memory actions are required of the flightcrew. An engine loss at cruise altitude and at cruise speeds does not place the airplane in immediate jeopardy nor, for the most part, are any immediate responses required of the flightcrew to retrieve the airplane from jeopardy. The facts of this accident confirm this evaluation since the loss of control did not occur until more than 3 minutes after the No. 4 engine had lost thrust. More than enough time was available to the flightcrew to react properly and prevent the upset. This fact was amply demonstrated on two previous flights for this airplane in which similar situations occurred; the malfunctions were corrected, and the airplane proceeded to scheduled destinations without further incident.

The Safety Board is aware of present and proposed National Aeronautics and Space Administration (NASA) studies on the effects of circadian desynchronosis on flightcrew performance and efficiency. NASA has recently concluded a study of the effect of circadian desynchronosis on the performance of flightcrews engaged in short-haul flights, but has not, to date, released its findings. A similar study on the effects circadian desynchronosis may have on the performance of flightcrews engaged in long-haul transmeridional flights was begun recently. Until the results of either or both of these NASA studies are released, the Safety Board believes that it would be premature to formulate any recommendations which address either the effects of circadian desynchronosis on flightcrew performance or which contain actions designed to counteract these effects based solely on the results of this investigation.

Although the Safety Board was unable to identify any problems associated with the lack of crew coordination during its analysis of the accident, it also believes the facts and circumstances surrounding the upset illustrate the many factors which can complicate the problems of a multiengine airplane's flightcrew during an inflight abnormality or emergency. The Safety Board believes that the ability of a flightcrew to identify correctly the nature of an emergency or abnormality and then to cope successfully with the identified mishap can be improved and facilitated by proper crew coordination. We also believe that the full benefits of proper crew coordination can only be achieved when the captain recognizes and makes full use of the resources available to him in his cockpit; i.e. the knowledge and training of his crew members. In order to train captains and crew members to recognize these resources and to utilize them to the fullest extent possible, the Safety Board has recommended that the FAA develop and implement a training program to accomplish this goal 21/. The Safety Board urges the FAA to complete the development of this program and to disseminate it to the industry.

3. CONCLUSIONS

3.1 Findings

1. The flightcrew was properly certificated and qualified.
2. The changing airspeeds encountered by Flight 006 and the resultant compensating throttle adjustments were caused by wind speed variations.
3. The No. 4 engine did not flame out, but "hung" at about 1.0 EPR.
4. During his attempt to recover the No. 4 engine, the flight engineer did not close the bleed air valve switch before advancing the No. 4 throttle.
5. The other three engines did not lose thrust nor did they flame out.
6. The captain did not disengage the autopilot in a timely manner after thrust was lost on the No. 4 engine. The autopilot effectively masked the approaching onset of the loss of control of the airplane.
7. The captain was distracted from his flight monitoring duties by his participation with the flight engineer in the evaluation of the No. 4 engine's malfunction.
8. With the exception of the loss of thrust on the No. 4 engine, no other airplane malfunction affected the performance of the airplane; the loss of thrust on the No. 4 engine did not contribute to the accident.
9. The captain was also distracted by his attempts to arrest the airplane's decreasing airspeed, and this also contributed to his failure to detect the airplane's increasing bank angle.

21/ Safety Recommendation A85-27, issued

10. The lateral control deflections required to maintain level flight under conditions of thrust asymmetry and decreasing airspeed exceeded the limits of the autopilot's lateral control authority, causing the airplane to roll and yaw to the right. The captain lost control of the airplane when, after disengaging the autopilot, he failed to make the proper flight control corrections to recover the airplane.

11. The damage to the airplane was a result of the acceleration forces and high airspeeds that occurred during the upset and recovery maneuvers.

3.2 Probable Cause

The National Transportation Safety Board determines that the probable cause of this accident was the captain's preoccupation with an inflight malfunction and his failure to monitor properly the airplane's flight instruments which resulted in his losing control of the airplane.

Contributing to the accident was the captain's over-reliance on the autopilot after the loss of thrust on the No. 4 engine.

4. RECOMMENDATIONS

None.

ICAO Note.— Section 1.17 and the Appendices were not reproduced.

ICAO Ref.: 022/85

No. 3

Fokker F-27 MK 100, YN-BZF, accident on the icecap of Greenland, on 20 April 1985. Report No. 4/87 released by the Department of Accident Investigation, Denmark

All times in this report are Universal Coordinated Time (UTC) = Greenland Summer Time + 2 hours.

Notification of the accident

The accident was reported to the Department of Accident Investigation, Civil Aviation, by the Flight Information Center at Søndre Strømfjord, Greenland on 20 April 1985 at 2238 hours.
The Nicaraguan Civil Aviation Administration was informed by ACCID* on 21 April 1985. The investigation was commenced at Søndre Strømfjord on Monday 22 April 1985, and the accident site was visited on 24 and 25 April 1985 for short periods.

Synopsis

YN-BZF was engaged on a delivery flight from North Yemen to Nicaragua. Part of the route had been planned via Iceland, Greenland and Canada. For the purpose of extended range two 200 US gal auxiliary ferry fuel tanks had been installed in the cabin of the aircraft. During the flight from Iceland to Greenland the crew informed the air traffic control that problems had arisen with retrieving fuel from the auxiliary ferry fuel system. Approximately 50 NM west of Kulusuk (BGKK) on the eastcoast of Greenland the crew decided to return to BGKK, but due to deteriorating weather conditions the aerodrome could not be located. The flight diverted hereafter westbound for an emergency landing at a radar station, "SOB STORY", on the Icecap. During descent the aircraft collided with the Icecap. 3 crew members survived the accident, and 2 crew members died from injuries inflicted during the crash. The aircraft was destroyed. The survivors and those killed were recovered from the Icecap on the following morning by a rescue team, which was flown to the site in a C-130 military rescue aircraft. This department concludes that the factors in this accident were unfavourable weather conditions at the diversion aerodrome and at the accident site, and the failure of the crew of YN-BZF to ensure proper airborne function of the auxiliary ferry fuel system.

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*ACCID: Notification message.

1. FACTUAL INFORMATION

1.1. History of the flight

YN-BZF was engaged on a delivery flight to Nicaragua. In the cabin of the aircraft an auxiliary ferry fuel system, consisting of two 200 US gal tanks with associated equipment, had been installed for the purpose of providing extended range. The system had been installed before departure from North Yemen. YN-BZF departed on 11 April 1985 from North Yemen (Sanaa) via Saudi Arabia (Jeddah), Egypt (Cairo) to Greece (Athens). The flight proceeded from Greece on 19 April 1985 via Italy (Geneva) to Scotland (Prestwick). On 20 April 1985 the flight proceeded from Prestwick via Stornoway to Reykjavik (Iceland) where it arrived at 1548 hours.

Since the crew had been unable to retrieve fuel from the auxiliary ferry fuel system during the preceding part of the flight, they checked the system during the stay at Reykjavik (BIRK), and they found it to be in working order. However, to ensure that the system functioned properly, experienced Icelandic F-27 engineers were consulted. The Icelandic engineers have explained that they had been consulted due to problems in making the fuel flow from the auxiliary tanks. They entered the cabin and observed two large round fuel tanks strapped down in the middle of the cabin, from which section the seats had been removed.
They discussed the system with the aircraft mechanic, who explained that it was connected to the cross-feed line on the wing front spar. (In a later interview the captain explained that the system was connected directly to the left fuel tank).
The fuel tanks seemed to the ground engineers to be well ventilated into the cabin, and the vents were connected with each other. A flexible line was coming from each tank connected to electrical booster pumps, one for each tank, and from the pumps there was a single line up into the cross-feed fuel line on the front spar, through the fuselage.
The ground engineers did not notice any fuel flow meter, fuel pressure meter or fuel quantity meter on this auxiliary system. They were told by the aircraft mechanic that the crew could not make the auxiliary ferry fuel system work. When asked what exactly had been done, the aircraft mechanic replied that they had put the ferry tank booster pumps "ON" and waited for the fuel quantity in the main tanks to increase, which had not happened. He explained that they had tested the booster pumps on the auxiliary ferry fuel system, and when they were "ON", the line connected to the cross-feed line did pressurize.
He was then informed by the ground engineers that he could not cross-feed from tank to tank, but only from tank to engine. To their question, whether the cross-feed valve had been opened, he answered "No", meaning that in fact only the cross-feed line to the cross-feed valve had been pressurized.
At this point of the conversation the rest of the crew arrived, the pilots and the navigator. They said that one of the two aircraft booster pumps had been "ON" all the time during flight, and during attempts to activate the auxiliary fuel tanks.

The ground engineers advised the crew to switch "ON" the fuel booster pumps for the internal auxiliary tanks, and at the same time open the cross-feed, and switch "OFF" the booster pumps for one engine at a time.
The captain said that he understood this, and that no further assistance or inspection was needed.
The ground engineers did not undertake any close inspection of the system and did not perform any maintenance work, but they advised the crew to land at Kulusuk for refuelling, which Icelandair usually did on their F-27 flights.
The mechanic was advised to make at least a 5 minutes' run-up on the ground from the internal tanks to each engine in order to ensure that the system was working, and that there was no air in the system. He agreed, and the engineers drove back to their premises and observed that the aircraft took off shortly after.
In the opinion of the ground engineers the auxiliary fuel system "was not very professionally looking" and they "got the feeling that the crew was not quite certain of how to operate it".

The flight planning to Søndre Strømfjord (Greenland) from BIRK was based and calculated on the normal aircraft internal fuel, and the additional fuel in the auxiliary ferry tanks was - to comply with IFR regulations - to be available for alternates. Hence the check of and concern for the system.

The aircraft uplifted 2704 litres of fuel, and was fuelled to capacity including 400 US gal in the auxiliary ferry fuel tanks in the cabin.
After having received weather information and ATC clearence, the crew took off from BIRK at 1721 hours. At 1832 the Pilot-in-Command of YN-BZF transmitted a message to Iceland radio, whom he asked to extend his thanks to the Icelandic engineers with the message that the auxiliary ferry fuel system was working correctly. This message was transmitted prior to passage of Kulusuk at 1935 hours.

Kulusuk non-directional beacon (KK) was passed overhead at 1935 hours. Approximately 50 NM west of KK the crew of YN-BZF radioed to the radar station BIG GUN about fuel problems, as it had been discovered that the auxiliary ferry fuel system did not function after all (1950 hours). Thus encountering a reduction of fuel reserves by approximately 400 US gal together with a ground speed of only 180 knots (calculated to 225 knots) the crew decided to return to KK for landing at Kulusuk aerodrome (BGKK).

In consequence of this situation BGKK was opened (closed over week-ends). However, weather conditions in the area were deteriorating, and by the time YN-BZF attempted a procedural approach to BGKK at 2008 hours, weather conditions were below the published minima of 8 kilometers visibility and 700 ft ceiling. The Obstacle Clearance Limit (OCL) for the procedure is 800 ft (688 ft).

Prior to initiating the approach the crew had requested the following information at 2001 hours:

YN-BZF: "What is the distance from the NDB KILO KILO to the airport?"

AFIS BGKK: "The distance from KILO KILO NDB is ten* miles, ten miles, the aerodrome is situated ten miles north of KILO KILO NDB - go ahead".

YN-BZF: "Thank you".

At 2006 hours the crew requested the bearing directly from the NDB to the runway. To this request the AFIS operator responded "negative, what are your level and what and what is your altitude?". The cloud penetration procedure was then read to the crew according to the published procedure.

At 2011 hours a let down to 800 ft was commenced, but in the first attempt the runway was not located. YN-BZF returned to the beacon, and maintained visual flight close to the beacon over the water. Again at 2023 hours the crew of YN-BZF transmitted: "What is a good heading directly from the NDB to the runway, please?", to which the AFIS operator again answered: "Negative, negative".

As the situation was developing into an emergency situation, the AFIS operator tried to assist the crew of YN-BZF by verbal explanation of the position of the aerodrome directly north of the beacon, and of the mountain peaks of the island in relation to the terrain. At 2038 hours the crew of YN-BZF tried to verify the position of the aerodrome related to the beacon, but at this point the AFIS operator did not volunteer any other procedure than the one published, and again the cloud penetration procedure was read to the crew of YN-BZF.

YN-BZF returned over the beacon and commenced a let down at 2042 hours. At 2044 hours the following message was transmitted from BGKK to YN-BZF: "With your remaining fuel in mind flight information Søndre Strømfjord advises you that you can go to DYE 3. DYE 3 it's one six eight miles and the track is three zero two degrees magnetic....". After the vain efforts to locate the aerodrome, the crew decided to follow the suggestion from the Flight Information Centre at Søndre Strømfjord (BGGL) of climbing over the Icecap and attempt a forced landing at the radar station "SOB STORY", located 168 NM west of BGKK. At 2051 hours YN-BZF left the Kulusuk area with remaining fuel for one hour's flight.** Weather conditions at the radar station (with prepared snow runways) were reported to the aircraft. Furthermore, QNH and a minimum safety altitude of flight level (FL) 110 were passed on to the crew of YN-BZF. An emergency was declared at 2115 hours.

When fuel indications became critical, decision was made to start a slow descent. The aircraft was IMC. The captain had ordered the engineer to work on the auxiliary ferry fuel system, and he was in the aft of the cabin. The captain has explained that he thought that an explosion occurred. The aircraft was filled with mist, it

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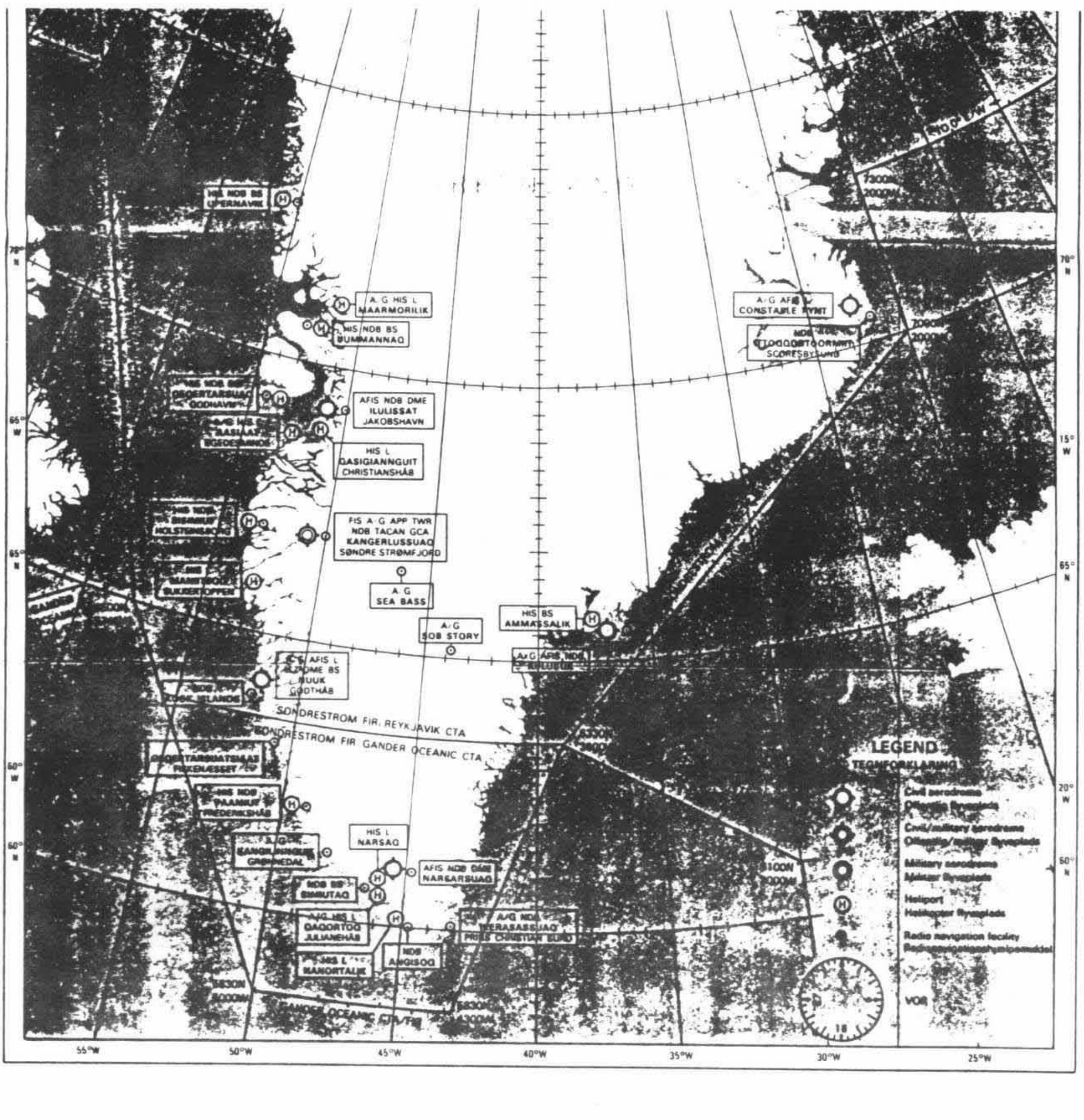
* The distance is 3 NM

** Detailed radio correspondence between BGKK and YN-BZF is depicted in Appendix B, and the let down procedure used by the crew of YN-BZF (Jeppesen: KULUSUK, GREENLAND) is depicted in Appendix C.

was smelling strongly of fuel, and subsequently he had difficulties in controlling the aircraft, and at last he lost control completely. He believed that the aircraft dropped several hundred feet before it finally hit the snow coat of the Icecap.
Speed of the aircraft was about 150 kts indicated when the collision occurred.
In answer to direct questions of knowledge of the height of the terrain, the captain indicated that it was about 4000 ft, and the navigator indicated a general height in the area of about 8000 ft.

YN-BZF collided with the snow coat of the Icecap at a height of 7400 ft. Radar and communication contact was lost at 2132 hours.



A rescue aircraft (military C-130 equipped with skies) was over the accident site at 2330 hours, but could not land on the Icecap due to darkness (twilight ending). Survivors were not sighted but landing attemps were to be made on the following morning at first daylight (0700 hours). The rescue aircraft landed on 21 April at 0710 hours. Of the 5 crew members 3 had survived. The rescue aircraft landed at BGSF at 0902 hours.

The accident occurred 28 NM east of the radar station at a position of 650950 North 0424130 West at an altitude of 7400 ft on 20 April 1985 at 2132 hours under daylight conditions.

1.2. **Injuries to persons**

Injuries	Crew	Passengers	Others
Fatal	2	-	-
Serious	2	-	-
Minor/none	1	-	-

1.3. **Damage to the aircraft**

The aircraft was destroyed.

1.4. **Other damage**

None.

1.5. **Personnel information**

1.5.1. The pilot-in-command (P-i-C)* - aged 38, male - held an Airline Transport Pilot's License (ATPL) renewed by the Civil Aviation Department, India on 19 March 1985, and it was valid until 1 June 1985.
The captain was last medically examined on 13 March 1985 with no limitations.
The captain survived the accident.

Flying experience:

	Last 24 hours	Last 30 days	Last 90 days	Total
All types	approx. 9	31	32	11668
This type	approx. 9	31	32	5000**

* P-i-C will hereinafter be called the captain
** Approximate time

1.5.2. The co-pilot - aged 27, male - held an Airline Transport Pilot's Licence (ATPL) validated on 20 March 1985 and valid until 20 March 1986.
The co-pilot was last medically examined on 21 March 1985 with no limitations.
The co-pilot was fatally injured in the accident.
Flying experience:

	Last 24 hours	Last 30 days	Last 90 days	Total
All types	-	-	-	2000*
This type	-	-	-	850*

1.5.3. In total the crew consisted of 5 persons of different nationality. Another pilot (not experinced on F-27) and the navigator survived the accident.
The engineer experienced on the F-27 was fatally injured in the accident.

1.6. Aircraft information

1.6.1. Relevant data on YN-BZF

Type:	Fokker 27.101
Model:	Friendship F 27 MK 100
Manufacturer:	Fokker VFW N.V. Kingdom of The Netherlands
Year of manufacture:	1959
Aircraft serial number:	10118
Certificate of airworthiness	Validated 7 March 1985 and valid until 7 March 1986
Certificate of registration:	Issued by the Civil Aviation Authorities in Nicaragua
Total airframe hours:	45225
Time since major overhaul:	Approximately 300 hours
Engines (2):	Rolls Royce Dart 529
Serial numbers:	Port (P): 5386 Starboard (S): 10127
Time since overhaul:	P: 4169 hours S: 3676 hours

* Approximate time

Time since new:	P: 46921 hours S: 43803 hours
Propellers (2):	Dowty Rotol 175-4-30-4/13E
Serial number:	P: Drg 59-201 S: Drg 58-74
Cycles since overhaul:	P: 3402 S: 5528
Cycles since new:	P: 44449 S: 46430

Weight and balance calculations for YN-BZF for this flight have not been performed due to missing and insufficient data.

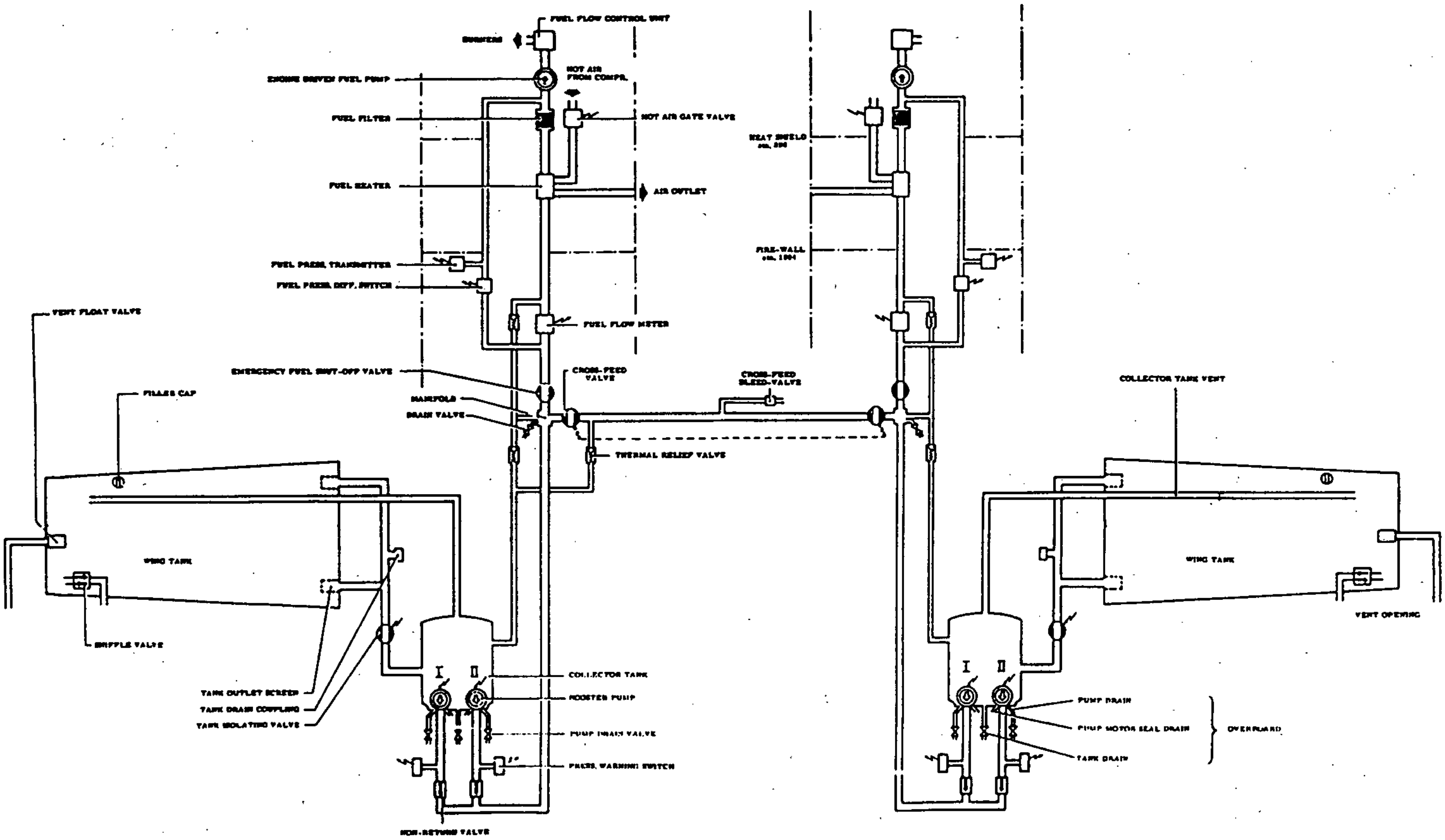
1.6.2. **Fuel System**

The F-27 fuel system comprises two independent systems, a port and a starboard system, with a total tank capacity of 2900 kg. Fuel is stored in two integral tanks (one in each outer wing), and in two collector tanks (one in each nacelle).
The systems are identical and are connected by a cross-feed line which incorporates twin cross-feed valves, manually operated from the cockpit.
A single knob is mounted at the rear of the cockpit pedestal, placarded "OFF" and "ON". Clockwise rotation of the knob opens both cross-feed valves simultaneously.
Normally, the port system supplies the port engine, and the starboard system supplies the starboard engine.
When cross-feeding, it is possible to feed both engines from the port system, or both engines from the starboard system. Transfer of fuel from one system wing tank to the other, however, is not possible.
The collector tanks, which are both fitted with two electrically driven, centrifugal booster pumps, ensure an uninterrupted supply of de-aerated fuel to the engine-driven fuel pumps in all attitudes of flight and at all operational altitudes, thus guarding against inadvertent engine "flame-outs" due to fuel starvation, and also preventing "cavitation" of the engine-driven fuel pump.

1.6.3. **Auxiliary Ferry Fuel System**

For the purpose of having extended range the aircraft was fitted with a "ferry kit", consisting of two 200 US gal drums interconnected. During flight this equipment was seemingly not working as expected, while ground operations were satisfactory according to the crew.

Due to the problems with the ferry kit, the aircraft had to return from over the Icecap to BGKK, where refuelling could be undertaken. Due to deteriorating weather conditions at that aero-



FUEL SYSTEM DIAGRAM

drome, a landing could not be performed, and the final result of the flight was the accident on the Icecap, which occurred when the aircraft was descending to prepare for a forced landing in the snow.
The tanks "exploded" (compression - no fire) on impact, and the cabin was demolished in that area.

From interviews with the crew it has been learnt that the aircraft mechanic installed the ferry kit in YN-BZF, and that he was assisted by another mechanic, who was employed with the Maldives International Airways. The aircraft mechanic was fatally injured in the crash.

In order to obtain information of the auxiliary tank installations from the other mechanic, this department made inquiries to the Maldives International Airways by letter of the 26th June 1985. An answer to this letter has never been received.

From the Fokker manufacturer this department has received the following information:

"Fokker has one ferry fuel tank set available for delivery flights, either new aircraft or overhaul. This system operates through cabin differential pressure, has no additional booster pumps, and feeds directly into the left main tank. Fuel balance is controlled through cross-feed selection.
It is known that some F-27 operators have employed different systems, possibly including additional booster pumps, from unknown sources, however, it would seem that the system involved in this case belongs to the latter category.

The above installation is available to customers on short term hire basis only. We have no record of this or similar systems having been delivered to F-27 operators.
Fokker have not been involved in the installation of the ferry tank system used on the subject flight."

1.6.4. Safety equipment

The amount of emergency equipment on board the aircraft for survival has not been established. According to the radio transmissions between YN-BZF and the radar station, the crew informed that they had "some life rafts and stuff like that..". From the wreckage one life raft was recovered. The life raft was checked, but neither emergency pyrotechniques nor separate emergency radio were stored in the life raft. Other emergency equipment might have been available, but was not found during the short search in the wreckage area. Some equipment may have been burried under the snow.

According to the Aeronautical Information Publication (AIP) for Greenland and the Faroe Islands, no special requirements are stipulated for this type of flight and aircraft except for emergency radio equipment. The flight plan received by Icelandic Air Traffic Control contained the following information: one dinghy, eight life jackets, polar and maritime equipment, and radio frequency 121.5 MHZ.

1.7. Meterological information

1.7.1. General

The crew requested the en-route weather from the weather office at BIRK. Based on a 500 mb prognose chart VT. 21/0000 the wind velocity en-route BIRK-BGKK-BGSF was issued. It was pointed out to the crew that the winds aloft (FL 180) were stronger than previously briefed (based on the chart VT. 20/1800). The winds would be southwest 45 kts, south southwest 50 kts and south southwest 30 kts respectively.

1.7.2. **Weather data**

Weather on 20 April 1985 1900-2200

BGKK area:

surface (sfc) wind	easterly/10-15 kts
visibility	8-10 km lowering from approximately 20 UTC to 3-4 km
weather	rain and snow mixed and distant fog
clouds	4/8 1000 ft and 7/8 2000 ft changing from about 20 UTC to vertical visibility 700-900 ft

Area 50 NM east of the radar station "SOB STORY":

sfc wind	NE-E about 5 kts
visibility	vis 500 m - 1500 m
weather	icefog/light snow
clouds	vertical visibility 100-400 ft

"SOB STORY":

sfc wind	variable/4-8 kts
visibility	800-1500 m gradu 20-21 UTC 5000 m gradu 21-22 UTC 7-10 km
weather	icefog/light snow gradu improving during period
clouds	vertical visibility 200-400 ft gradu late in period changing to sct/bkn sc base 3-4000 ft

BGSF:

sfc wind	westerly 12-15 kts rapid changing to northeasterly 10-15 kts
visibility	above 10 km
weather	fair from 21 UTC cloudy
clouds	1-2/8 ac base 8000 ft gradu 21-22 UTC 6/8 5000 ft

1.7.3. **Weather en-route BGKK - "SOB STORY" - BGSF 1900-2200 UTC**

BGKK - "SOB STORY"

Clouds: Near BGKK base/vertical visibility 700-900 ft top about 15000 ft - just west of BGKK base/ vertical visibility lowering to 100-400 ft top 13000 ft.

Weather:	overcast with precipitation as rain and snow on the eastcoast, and as light snow on the Icecap. Icefog many places on the Icecap.
Visibility:	8 km near BGKK rapid after 19 UTC lowering to 3-4 km. On the Icecap visibility 500-1500 m.
Freezing level:	1000-1500 ft near BGKK dropping to surface just west of BGKK.
Icing:	occasionally light/moderate rime ice in clouds.
Turbulence:	light.

"SOB STORY" - BGSF:

Clouds:	scattered sc/ac base above 3000 ft but during period broken/overcast sc base on the Icecap 2-3000 ft and near BGSF 5000 ft, top FL 130.
Weather:	fair becoming cloudy to overcast during period.
Visibility:	above 10 km.
Freezing level:	on or near surface.
Icing:	nil but light rime in clouds late in period.
Turbulence:	nil

1.7.4. **Upper winds**

Route	FL 180	FL 100
BGKK - "SOB STORY"	210/45 ms30	190/20 ms14
"SOB STOTY" - BGSF	210/20 ms30	180/15 ms14

1.7.5. **Actual weather (radioed to YN-BZF)**

BGKK 1919:	visibility 8 to 10 km 4/8 1000 ft 7/8 2000 ft
1928:	180°/10 kts visibility 10 km 4/8 800 ft 7/8 2000 ft
1955:	visibility 4 km vertical visibility 900 ft fog and rain, weather lowering
1957:	180°/15 kts visibility 4000 m in rain and fog vertical visibility 800 ft QNH 1013 mb
1959:	180°/14 kts visibility 4000 m in rain light rain and fog vertical visibility 700 ft
2002:	wind calm visibility 2500 m rain and fog vertical visibility 400 ft and (new) 180°/11 kts visibility 4000 m in rain and fog vertical visibility 700 ft

2003: QNH 1013 mb equal to 2991 inches
2032: estimated vertical visibility above BGKK 1000 ft

"SOB STORY":
2055: visibility 3 NM winds 2 kts 140°T +12°F
2112: actual 2050 300 ft overcast visibility 3 nm in icefog wind 140°/2 kts QNH 3008 inches temperature 12°F

1.7.6. **Light Conditions**

SUNSET	20 April 1985: 2241 hours
TWILIGHT ENDS	20 April 1985: 2345 hours
TWILIGHT BEGINS	21 April 1985: 0552 hours
SUNRISE	21 April 1985: 0703 hours

1.8. **Aids to navigation**

1.8.1. **In the air**

YN-BZF was equipped with the radio navigational equipment that is required and applicable for such flight. The aircraft was neither equipped with radio altimeter nor with a ground proximity warning system.

1.8.2. **On the ground** (pertinent to the accident)

Radio beacon "KK" 283 KHZ positioned 653147 N 0370923 W. Radar station "BIG GUN" in the Kulusuk area (this radar cannot provide guidance for approach into low level part of approach to BGKK).

Radar station "SOB STORY" on the Icecap about 168 NM West of BGKK.

1.9. **Communications**

YN-BZF:	VHF and HF radio.
BGKK:	118.1 MHZ, 121.5 MHZ and 5526 KHZ.
BGSF A/G:	121.3 MHZ, 2950 KHZ, 5526 KHZ, 8945 KHZ and 10042 KHZ.
"BIG GUN":	122.2 MHZ and 121.5 MHZ.
"SOB STORY":	122.2 MHZ and 121.5 MHZ.

All radio communication and telephone conversation (selected line numbers) have been recorded and transcripts are available.

YN-BZF was in radio contact with BGKK, SF A/G (FIC, BGGL), "BIG GUN" and "SOB STORY".

Assistance to YN-BZF was coordinated between BGSF, BGGL, BGKK, "BIG GUN", and "SOB STORY".

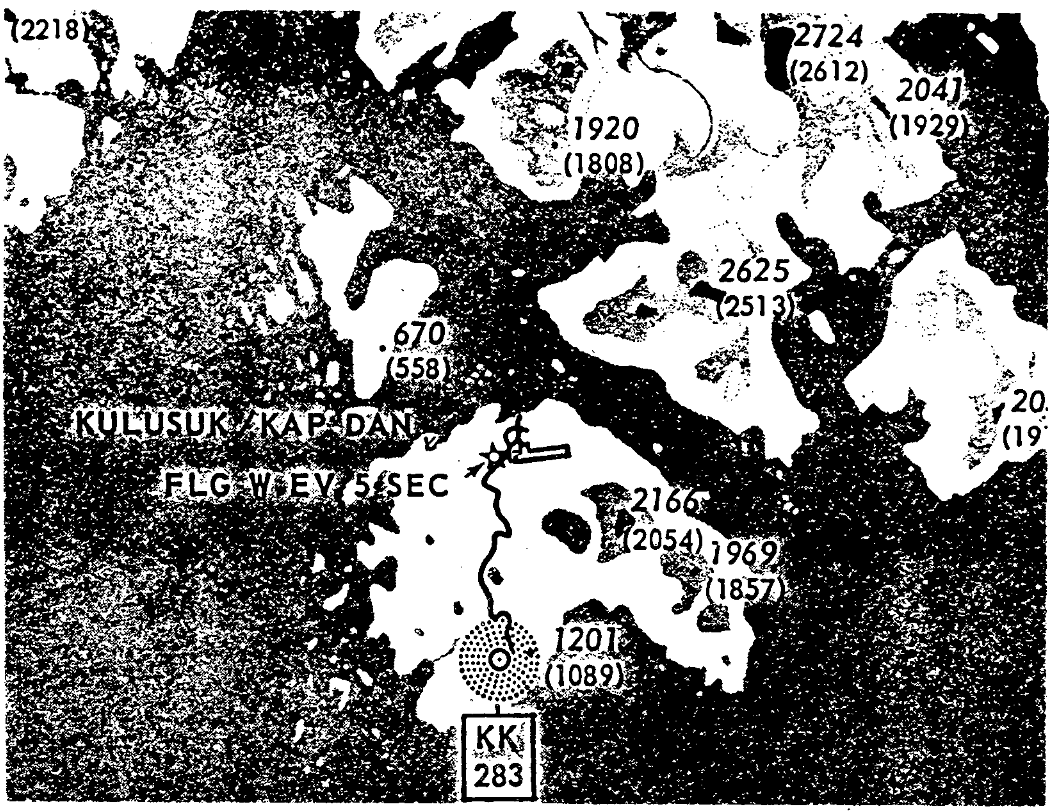
1.10. Aerodrome information

Kulusuk aerodrome (BGKK) is situated at the position 653425 N 0370725 W. Elevation is 112 ft*. Variation is 32° W (1985). Runway designation is 12/30. The gravel runway is 1190 x 45 m. The runway is equipped with treshold, edge and end lights.

The aerodrome is open during weekdays (monday-friday) 1000-1800 hours. Operation before and after these hours requires a prior notice of 2 hours, or as soon as possible in case of an emergency.

For operation the following State minima applies:

Approach (day only) runway 12/30, ceiling 700 ft, ground visibility 8000 m.



*Elevation is in feet above mean sea level (AMSL)

The aerodrome is situated in a mountainous area in the northern part of an island in the Ammassalik Fjord. Highest peaks on the island are 2166 ft and 1969 ft. All obstructions on and near the aerodrome are provided with red lights. The beacon "KK" is situated in the southern part of the island. The distance to the aerodrome is 3 NM from "KK" in a bearing of 035° magnetic.

The "SOB STORY" radar station is located at the position 6511 N 04350 W. Close to the radar station is a marked and cleared runway in the snow, length 6250 ft and 5000 ft overrun. Runway lights are not provided. The runway is normally used by ski-equipped aircraft. Elevation is 8241 ft.

1.11. **Flight recorders**

YN-BZF was equipped with a Daval type 1191 flight data recorder (FDR), and a United Control model V 557 cockpit voice recorder (CVR) part no. 1835.

1.11.1. **Flight Data Recorder**

The flight data recorder was recovered from 1/2 m below the snow close to the separated tail section of the aircraft. The flight data recorder was not active during the flight. The data that were derived from the recorder dated from a previous flight, which origin has not been established. The reason for the recorder not being serviceable/activated has not been established, as investigation of the wreckage was very limited, due to the short time available at the accident site.

1.11.2. **Cockpit Voice Recorder**

The cockpit voice recorder was recovered from the surface of the snow about 40 m from the separated tail section of the aircraft. The recorder contained a recording of the last 30 minutes of the flight. (The minutes up to and including the accident were recorded). The recording was of good quality and most of the data were clearly presented. The quality of the radio communication reception in the area sometimes varies.
The intelligibility of the correspondence from the aircraft also varies, depending on the nationality of the person speaking. The captain, who is of Indian nationality, is at times rather difficult to understand, while the navigator, who is of American nationality, is clear in his wording.

1.11.3. **Data from the Voice Recorder**

The voice recorder data reveal that the crew was informed on matters of importance for the intended emergency landing at "SOB STORY". The crew of YN-BZF was informed of the length of the packed snow-runway of 6250 ft with an overrun of 5000 ft, of present weather conditions in the area, of altimeter setting in inches, of current distances and bearings to the radar station, of

the aircraft's ground speed, and of the smooth terrain leading up to the radar station from 30 miles out; the terrain was rough at about 40 miles out of the station.
To an inquiry concerning emergency equipment on board, the crew informed that "some compasses and life rafts and stuff like that and warm clothing" were available.
At about 2127 hours the crew was informed that Search and Rescue would soon be airborne, and that the team consisted of Air Force C-130 aircraft.

The tape does not clearly reveal any information about altitude of the runways at the radar station, but in a passage of a message at 2126 hours the following wording is used by "SOB STORY": "You are still landing on the ice, it's all packed ice, you are landing about 9000 ft, over". The crew did not make inquiries for such information. At an earlier stage (at 2055 hours) the crew was informed by "BIG GUN" radar station that the minimum safe altitude was flight level 110.

About 2102 hours a slow descent was initiated from 9000 ft with about 150 KIAS, when about 30 miles out of BGKK. At 2131 hours the recorder presents a series of sounds spaced over 21 seconds (sound 1 is 0 seconds, sound 2 is 3 seconds later, sound 3 is 2 seconds later, sound 4 is 3 seconds later and sound 5 is 13 seconds later).
These sounds have been interpreted to represent contact with the snow (at 7400 ft AMSL) in the slow descent, a fairly light contact the first 3 times, and then a heavier contact (impact no. 4), and the last impact (no. 5.) with final disintegration of the aircraft. Shortly before contact with the snow the wording "seventy-five feet" is heard on the tape. This could indicate that the descent at this time was about 75 ft/min. There was no radio altimeter in the aircraft.

1.12. Wreckage and impact information

1.12.1. The accident site

The accident occurred on the Icecap at an altitude of 7400 ft. At the time of the accident the snow coat was fairly soft to a depth of approximately 50 cm and smooth and almost level. The position of the accident site is 140 NM west southwest of BGKK, 220 NM southeast of BGSF and 28 NM east of "SOB STORY".
On the 24th April access to the accident site was established from BGSF by a ski-equipped USAF C-130. Time available for investigation and collection of different items was limited to about 40 minutes, due to aircraft operating conditions in the soft snow. On the following day an inspector went to the site by helicopter from BGKK, and stayed at the site for about 1.5 hours. Therefore only a cursory examination of the wreckage was possible. Due to this limited time factor the investigation was focused on type of impact and essential areas of interest to establishing the reason for the collision with the snow. The auxilia-

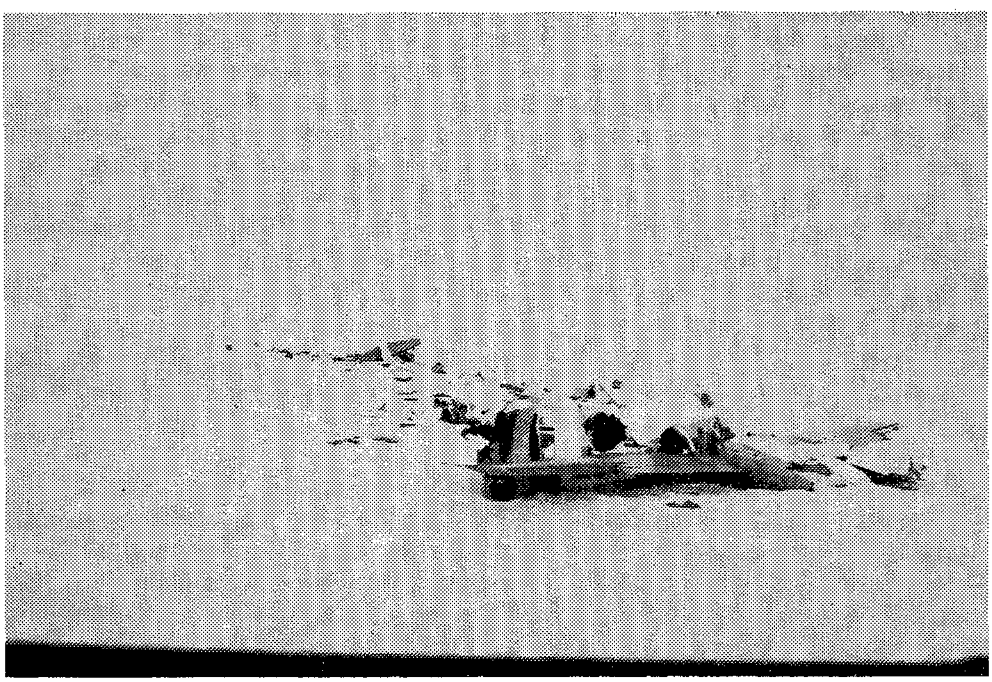
ry ferry fuel system installation could not be investigated as the ferry tanks had disintegrated and the installation into the main fuel system was inaccessible.

From the CVR it has been concluded that the aircraft hit the snow coat in a slight descent with about 160 kts, made 3 consecutive shortly spaced touches followed by impact no. 4 and no. 5, which resulted in the final disintegration of the aircraft. The point of impact no. 4 was observed, when the C-130 was taxiing approximately 500 m east of the position of the final impact. This impact area showed that the aircraft underbelly had impacted in what appears to have been almost level flight attitude, and debris of metal were visible. The final impact area was approximately 15 m long and 1.5 m deep. Propeller slash marks in the snow were sufficiently visible to show that the engines had been under power during the impact sequence. It was not until the CVR data became available that impacts no. 1 to 3 were revealed.

1.12.2. The wreckage

The aircraft fuselage had disintegrated and had been scattered along the wreckage path, which was approximately 190 m long in a fairly straight line on a heading of 286° magnetic. In the final impact hole wreckage parts from the lower structure of the fuselage were found. Propeller marks still visible measured about 150 cm with deeper cuts on the left side.

The left hand propeller had detached from the engine, while the right hand propeller was still attached to the engine. The tail section was found 60 m behind the final impact hole in an inverted position. From this position seats, interior material, luggage, and clothing had been spread in a narrow angle of about 10°



further up to the main wreckage. The aircraft fuselage had disintegrated, and had been scattered along the wreckage path. The entire wing section had catapulted to the left of the fuselage path of travel, and had come to rest in line with the path of debris, with the engines facing inwards at a distance of 130 m, with a 40 ft section of the front fuselage belly section on top. The aircraft nose section had severed from the fuselage 1 metre aft of the flight deck bulkhead, and was resting on its left side at the end of the left wing section at an angle of almost 90°.
The underside of the cockpit section showed signs of heavy compression from impact forces. The left pilot seat had been damaged (buckled), while the right hand seat was intact. Harnesses on all seats were intact. (Appendix D).

The on site investigation disclosed no further failure in the aircraft systems, structures or power plants. The defect right hand cockpit window electrical de-icing system, and the "failure" of the auxiliary ferry fuel system were reported by the crew; no other failures important to operation of the aircraft were reported.

1.12.3. Cockpit documentation

Pertinent cockpit documentation was as follows:

	Captain (LH)	**Co-pilot (RH)**
Airspeed	0 kts	0 kts
Horizon	left tilt	right tilt
Altimeters	1020 mb/30.11 inch.	1013.5 mb
Altimeters (24 April)	7700 ft	4600 ft
Rate of climb indicator	20 ft/min descent	20 ft/min climb
Gyrosyn compass	110°	090°
ADF/VOR hdg.card	245°	305°
Heading selector	280°	...
Alternate static select	NORMAL	...
Fuel quantity gauges	...	left 1000 right 0
Gear selector handle	UP	...
Cabin height	...	7000 ft
	Center panel	
Fuel flow	both 0 indication	
Fuel totalizer	left 1357 kg right 1379 kg	
Flap indicator	0	
Feather buttons	unfeathered	
	Pedestal	
High pressure cock	full forward	
Throttles/prop. handles	full forward	
Flap handle	UP	
Cross-feed selector	OFF	

	Right hand side console	
Cabin pressure control	selected to 500 ft	
	Right hand overhead panel	
Booster pump switches	Port	Starboard
	Left ON	Left OFF
	Right OFF	Right OFF

1.13. Medical and pathological information

The captain received injuries during the crash which made him unable to move. During the night's stay in the wreckage, he further received frost-bite , which later required minor operations.
The extra pilot received several bone fractures, which made him unable to move, he also received frost-bite , which later required minor operations.
The navigator received only minor injuries.
The co-pilot received severe injuries from which he died about 8 hours later.
The engineer, who had been working at the auxiliary ferry fuel system in the cabin area, received fatal injuries during the disintegration of the cabin. He died a few minutes after the accident.

1.14. Fire

There was no fire.

1.15. Survival aspects

1.15.1. Survival

The comparatively small rate of descent of the aircraft during the impacts with the fairly soft snow coat of the Icecap made the accident survivable for those crew members who had strapped into their restraint systems and occupied the cockpit section. The captain occupied the left seat, the navigator the right seat and the extra pilot the centre seat. The occupants of the cabin area were exposed to forces which, due to a compression explosion of the 2 x 200 gallons auxiliary ferry fuel tanks and the pressurized cabin, fatally injured the co-pilot and the engineer.

The temperature reported at the time of the accident was minus 11^{o} C, and during the night the temperature dropped further to about minus 30^{o} C. Clothing carried on board the aircraft had been scattered in the area and could not be retrieved by the crew, who was thus without any warm protection against the cold, except for a single blanket. During the night's stay, the surviving crew members occupied the cockpit.

The life raft, which had been reported to be on board, was found on the accident site by the investigation team. The life raft did not contain any equipment for attracting attention, i.e. radio or flares.

1.15.2. **Search and Rescue**

The following is an excerpt - as valid at the time of the accident - of the AIP Greenland and Faroe Islands concerning Search and Rescue agreements and procedures:

"By agreement between the Danish Government and the Government of the United States of America, the latter has assumed certain responsibilities for assisting in Search and Rescue activities within the Search and Rescue Area (SRR) established in Greenland. The vast dimensions of the Search and Rescue Area, the climate and nature, the scarcity of population, and the communication problems necessitate not only a close cooperation between the various authorities in Greenland, but also prompt action from the nearest agency capable of rendering assistance.

The organization of the Search and Rescue service is therefore based upon the assistance of all available services and authorities in Greenland as well as upon requests for assistance from sources outside Greenland.
Søndre Strømfjord ACC will act as Alerting Centre for aircraft in need of Search and Rescue within Søndre Strømfjord SRR (FIR). The Senior U.S. Air Force Officer at Søndre Strømfjord will initiate SAR actions and act as "On Scene Commander". When deemed necessary, he will request the nearest USAF Air Rescue Squadron Rescue Coordination Centre to provide a SAR-Coordinator, who will take over the direction of the SAR action.

The direction of Search and Rescue operations will be carried out in close cooperation with the Coordination Centre for the Sea Rescue Service in Greenland waters - Grønnedal - which may act as Rescue Sub-Centre.
Danish ATS units or other appropriate services in Greenland will act as alerting posts and may by agreement between them and the appropriate Rescue Services (Søndre Strømfjord, Thule or Grønnedal) act as Rescue Sub-Centre, should this be required."

USAF C-130 aircraft were present in the Greenland area at the time of the accident. The aircraft were at BGSF when the decision to initiate Search and Rescue procedures was made. One rescue aircraft was placed on stand-by at 2058 hours, which was 34 minutes before the accident occurred. The aircraft are equipped with skies and can operate on the Icecap if prior assessment of the area can be made. In rescue missions in areas which have not been assessed, it is the captain of the aircraft who has the final decision, whether conditions permit landing in the terrain. Under such conditions another C-130 will circle overhead as back-up aircraft.

No equipment is available at the radar station apart from snow cars, but for safety reasons these are, due to equipment range, limited to operation within a few miles from the radar station, and they could not be used as a tool for Search and Rescue in connection with this accident.
The Rescue Centre at Keflavik, Iceland can, if the situation warrents, assist with para-medics. In this particular case this option was not put into effect, due to weather conditions, darkness, and the time span for reaching the accident site as compared to the planned landing of the C-130 at first daylight (see appendix A).

The rescue aircraft were airborne BGSF at 2158 hours/2235 hours, and the first aircraft initiated search at 2300 hours. Radar contact with the wreckage was obtained at 2320 hours, and the rescue aircraft was over the accident site at 2330 hours.
Sunset in the area was at 2241 hours, and end of twilight was at 2345 hours.
When the crew of the C-130 spotted the wreckage, no survivors were visible, and no actions for attracting attention by visible means were detected. The crew radioed the observations to Søndre Strømfjord FIC. The area was uncharted and visibility was poor due to darkness and weather. It was considered unsafe to attempt landing, because of darkness and inability to assess snow and terrain conditions. Several passes were made over the wreckage, and during the last pass the crew prepared to drop a survival package just in case there should be survivors. At this time the accident site was engulfed in darkness which prohibited the drop.

The rescue aircraft left the area at 0030 hours and landed at BGSF at 0123 hours. Even though there were no signs of survivors, Search and Rescue would continue until there was proof, and thus Search and Rescue was resumed on the following morning with the aircraft circling over the accident site at first daylight (0700 hours). A survivor was spotted beside the wreckage, and landing was performed after an evaluation of terrain, snow conditons, pattern of debris from the wreckage, and wind conditions. 3 survivors were rescued and 2 casualties were retrieved from the wreckage. The rescue aircraft took off from the Icecap at 0745 hours and landed at BGSF at 0902 hours.

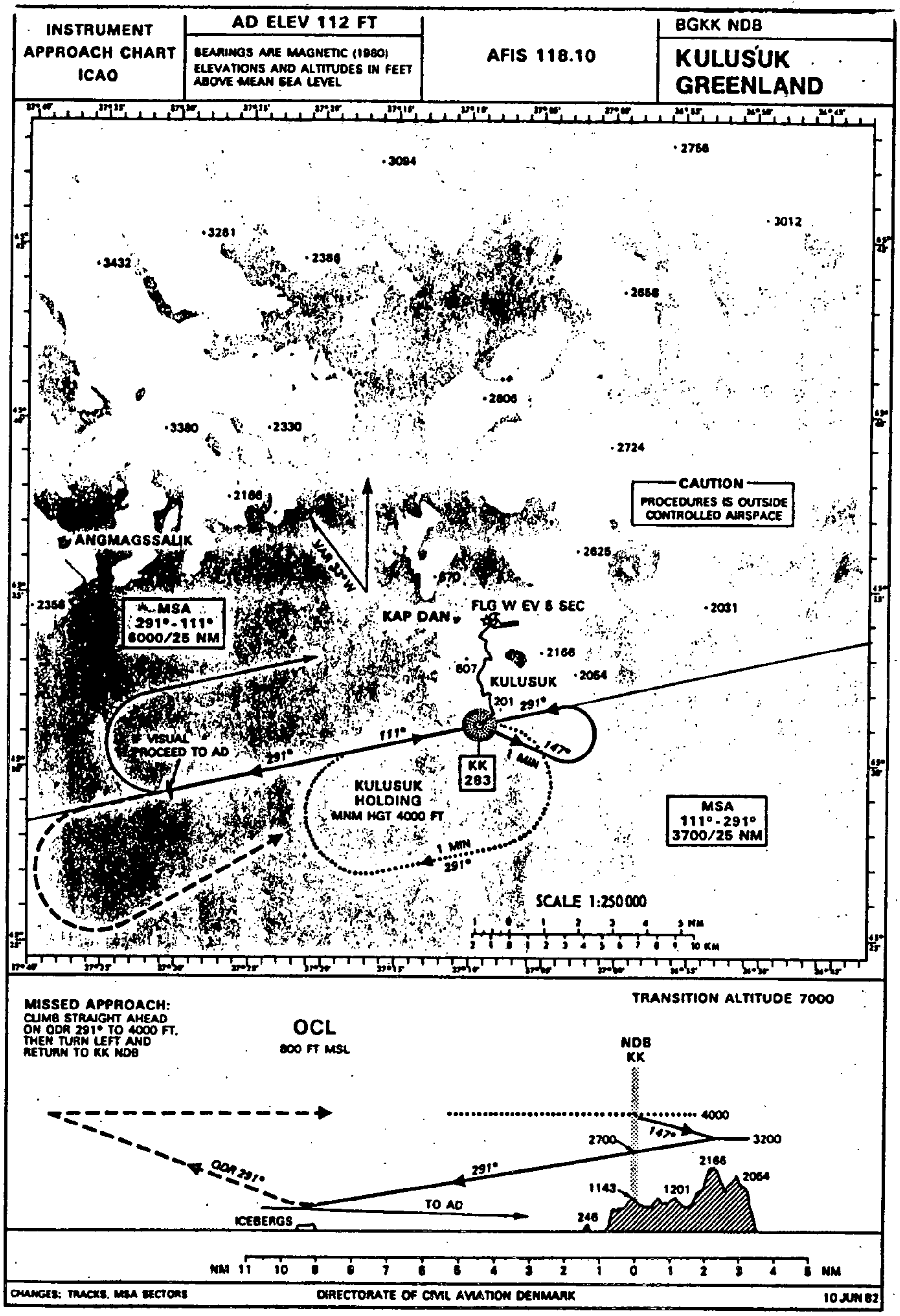
1.16. Test and research

No special test and research was undertaken.

1.17. Other information

1.17.1. Procedures at BGKK

The approach procedure for BGKK is published in the Aeronautical Information Publication Greenland and Faroe Islands:



The procedure is based on visual approach only, and the State minima for an approach require a ceiling of 700 ft and a ground visibility of 8000 m. The minimum safe altitude and the altitude of mountain peaks in the area are published.

The procedure is also published in Jeppesen Airway Manual as KULUSUK, GREENLAND NDB dated 2 July 1982. This plate was used by the crew, and all data valid for the approach to and landing at BGKK were depicted.

The Civil Aviation Authorithy (CAA) in Denmark has issued regulations for the AFIS regulated aerodromes. These regulations confine the scope of assistance of the AFIS operator to passing relevant and/or published information to air crews approaching BGKK. Instructions of KK NDB cloud penetration procedure should be given only on request from an aircraft commander, and in situations when the AFIS operator estimates an aircraft commander's knowledge of the procedure to be insufficient.
Control of aircraft is thus not the duty of the AFIS operator, and he is not authorized to guide aircraft on any other procedure, i.e. guidance directly from the KK NDB over the mountains to the aerodrome.
However, the phraseology to be used if an aircraft commander requests information is contained in the instructions for the AFIS operator at BGKK.
An excerpt of these instructions is depicted below:

"**Cloud penetration procedure for KK NDB**

The below procedure and phraseology is to be applied when information is requested by an aircraft commander, who is unfamiliar with the cloud penetration procedure:

a. At the earliest possible opportunity and before the aircraft leaves KULUSUK holding at the latest, the following general information is given:

Frequency for KK NDB is 283 KHZ - the aerodrome is situated 3 NM from KK NDB in bearing 035° mag. - runway in use.... aerodrome elevation 112 feet.

b. Before the aircraft commences descending from cruising altitude the following information of KULUSUK holding is given:

Join KULUSUK HOLDING at altitude 6000 feet on QNH ... millibars - inbound track 111° mag., right hand pattern, outbound time one minute - when established in the holding descend to altitude 4000 feet - report established in the holding and maintaining altitude 4000 feet.

c. When the aircraft reports established in the holding at 4000 feet, the following is informed:

Proceed outbound KK NDB on QDR 147° for one minute and descend to altitude 3200 feet, then turn left and proceed inbound KK NDB on QDM 291° and continue descend to altitude 2700 feet report established on QDM 291° and maintaining altitude 2700 feet.

d. When the aircraft reports established on QDR 291° - 2700 feet, the following is informed:

Proceed outbound KK NDB on QDR 291° - when passing KK NDB descend to altitude 800 feet - when visual turn right to heading 111° mag. - you will then find the aerodrome in front of you or a little to your left - if not visual at altitude 800 feet climb on QDR 291° to altitude 4000 feet, then turn left and return to KULUSUK HOLDING - report visual or going around.

NOTE: Instructions of KK NDB cloud penetration procedure should be given only on request from an aircraft commander, and in situations when the AFIS operator estimates an aircraft commander's knowledge of the procedure to be insufficient."

1.17.2. **Auxiliary ferry fuel system, mode of operation**

It has not been clarified how the ferry fuel system was installed in YN-BZF, and this department has not succeeded in obtaining data on this particular installation. From the description given in 1.6.2., two different systems are of relevance in this particular case:

- one system connected to the aircraft cross-feed system and
- one system connected directly to one of the wing fuel tanks (this system is recommended by the manufacturer).

System connected to the cross-feed

A system, connected to the aircraft cross-feed system, including two fuel booster pumps, requires for system functioning that:
- cross-feed valve is OPEN
- auxiliary ferry tank system booster pumps are ON
- booster pumps in aircraft collector tanks are OFF.

The procedure should ensure that fuel is transferred directly to the engines. Wing tank fuel content indications will not show an increase, but only indicate that no further fuel is drawn from these tanks.

System connected directly to a wing fuel tank

A system connected directly to a wing tank with booster pumps (booster pumps are not normally incorporated according to the Fokker manufacturer, para. 1.6.3.) requires for system functioning that:
- auxiliary ferry tank booster pumps are ON
- booster pumps in aircraft collector tanks are ON (as for normal operation)
- aircraft fuel balance is controlled by use of cross-feed to operate both engines from the left tank. Using this system, the wing tank fuel indicator would indicate an increase in the fuel contents of the wing.

If no booster pumps had been installed, the feeding of fuel to the wing tank would take place by means of differential air pressure (cabin).

2. ANALYSIS

2.1. The flight

In order to deliver an aircraft of this type from the area of initial departure in Yemen to the intended destination in Nicaragua, the route that can be planned will involve fairly short stops, as did the route planned for this delivery flight. The internal fuel of this aircraft would not be sufficient for executing the part of the route that comprises the flight from Iceland to the western part of Greenland, if the flight should be performed in accordance with the rules for IFR flights, and the amount of fuel required for reaching alternate aerodromes. Therefore the auxiliary ferry fuel system was installed in YN-BZF.

According to the captain's calculations the flight from BIRK, Iceland to BGSF, Greenland could be performed with the fuel available in the normal aircraft fuel system, but in this case fuel reserves when reaching BGSF would only be sufficient for another 5 to 10 minutes' flight. Also the ground speed of 180 kts (instead of 225 kts as calculated) as obtained through "BIG GUN" became a factor. The crew's decision of returning to KK NDB for landing at BGKK was influenced by these factors.

This department has made no weight and balance calculation for YN-BZF, but on the basis of the general description of the loading of the aircraft, it is believed that weight and balance was within limits and has not been considered a factor in this accident.

The flight was assisted and controlled by proper units, and the regulations and procedures applied by these units were satisfactory, except for erroneous information about the distance from the KK NDB to the aerodrome (10 NM instead of 3 NM) given by the AFIS operator at BGKK to the crew of YN-BZF, (see para. 2.3. The approach to BGKK).
Otherwise, it is the opinion of this department that the assistance rendered in an effort to create a reasonable and safe outcome of the situation was professional.

At 1911 hours, when the position was east of BGKK, the crew of YN-BZF informed BGSF that a diversion to BGKK could be a possibility to check out the auxiliary ferry fuel system. At 1935 hours YN-BZF passed the KK NDB westbound. The weather at BGKK was well within the minima required for approach and landing. At this time the crew had not yet decided upon the the course of action to be taken, as they suspected that the auxiliary ferry fuel system did not function as expected.
The decision to divert to BGKK was reported to BGSF at 1954 hours. At that time YN-BZF was approximately 50 NM west of BGKK.

2.2. **The auxiliary ferry fuel system**

This department has not been able to establish - neither from interviews nor from the short investigation of the wreckage on the Icecap - exactly how the system was interfaced with the aircraft fuel system, or why the system did not function (see para. 1.6.3.). The reason for the failure has thus not been conclusively established.

However, this department believes that the system was connected to the aircraft cross-feed fuel system, and that the crew did not realize that the system could have functioned if proper procedures had been applied. This belief is supported by the statements given by the Icelandic maintenance people, who inspected the system and advised the engineer of YN-BZF of how the system could operate. They also expressed the advise of making at least 5 minutes' ground run before take-off, using the system for each engine to ascertain that it was functioning properly, and that no air was present in the fuel lines of the system.

This advise was probably not followed, as the aircraft was seen to depart immediately after taxiing to the active runway (para. 1.1., para. 1.6., and para. 1.17.2.).

The crew radioed back to Iceland (1832 hours) that the system was functioning, and asked that their thanks be extended to the Icelandic maintenance people.

It is not clear what indications the crew had of the system functioning, but switching ON the fuel pumps of the system would of course produce a pressurization of the fuel lines from the ferry tanks which could be felt. If the system was connected directly to the left wing tank the indication of fuel contents in that tank would most probably increase.

If the system was connected directly to the aircraft cross-feed system, switching ON the booster pumps of the system would for proper function require the cross-feed to be selected ON, and the booster pumps in the collector tanks to be switched OFF in order to ensure fuel flow from the ferry tanks. The indications in the wing tanks would remain at last settings as no fuel would be transferred to the tank, and no fuel would be consumed from the tanks.

This department is of the opinion that the system would probably have worked if correct understanding of the system had been realized and therefore also correct procedures had been applied. Furthermore, this department believes that a functional airborne test-flight would have been a sound decision in order to ensure correct function of a system that is so vital for carrying out flights over long distances that require extra amounts of fuel. This was not done. Only some ground inspection and activation of the system was made, but environmental factors such as outside air pressure versus cabin pressure, and the technical influence of all systems related to appliance of the ferry fuel system with engines running and fuel booster pumps being activated/deactivated were - as far as this department has been informed - never tested in-flight. If a one-way check valve system was incorporated in connection with the ferry tanks (this has not been verified), reversely installed valves would prevent fuel from being tranferred from the ferry tanks. No such valves were observed by the Icelandic maintenance people, and no other information was obtained of such valves. This theory, however, can neither be proven nor rejected.

2.3. The approach to BGKK (Kulusuk aerodrome)

BGKK was opened for approach for YN-BZF outside normal opening hours as the transfer fuel problem was considered essential to the safety of the aircraft.

When the crew of YN-BZF decided to return to BGKK for refuelling the weather conditions were deteriorating rapidly. At the time the crew reported the intention of returning to BGKK (1954 hours) the weather was 4 km visibility and 900 ft in rain and fog. At 1957 hours: 4 km visibility and 800 ft vertical visibility in rain and fog. At 1959 hours: vertical visibility 700 ft. At 2002 hours: 2500 m visibility and 400 ft vertical visibility. YN-BZF was overhead KK NDB at 2008 hours.

The let down/cloud penetration procedure into BGKK is based on VMC conditions with set State minima of a ceiling of 700 ft and 8 km visibility. In weather conditions below these minima, the procedure can be hazardous to execute due to the mountainous area and the scarcity of electronic facilities for assistance and guidance. The aerodrome, situated in the northern part of the island approximately 3 NM north of the KK NDB, can be difficult to locate under conditions of low visibility, as the runway is very often covered with snow, and apart from a few buildings the surrounding environment is normally also white during this part of the year. Runway lights are available and were lighted during the approach. A good interpretation of the surroundings and the location of the aerodrome using maps and approach plates, however, is essential for crews who have never been in the area before. If such measures are undertaken, locating the aerodrome should offer no difficulty. Without such measures, locating the aerodrome could be difficult even at or above the weather minima required. However, this approach was performed under weather conditions that were considerably below the required minima, and therefore it was essential that the area was "understood" and that the approach was performed very accurately. YN-BZF was heard by people at the aerodrome but not sighted, even though the aircraft landing lights were on. The crew did not see the runway and returned over the water to the beacon and circled visually at about 1000 feet, close to the mountains. The vertical visibility was probably varying as YN-BZF was able to circle visually at 1000 ft close to the beacon, and the AFIS operator did report (2032 hours) an estimated vertical visibility of 1000 ft over the aerodrome. The AFIS operator advised YN-BZF of minimum safe altitude north and south of the aerodrome.

At 2012 hours the crew of YN-BZF had requested "BIG GUN" to guide the aircraft to the aerodrome, but such assistance could not be rendered by the radar station due to its position and to ground clutter. Thus YN-BZF was not guided by the radar station in its flight at low level.

The crew also requested the AFIS operator at BGKK* to give the heading and distance from KK NDB directly to the aerodrome. In accordance with regulations such information can be given. (See para 1.17.1. "Cloud penetration procedure").

To an inquiry from the crew of YN-BZF (2001 hours) for the distance from KK NDB to the aerodrome, the AFIS operator gave the following answer: "The distance from Kilo Kilo NDB is ten miles, ten miles. The aerodrome is situated ten miles north of..."
This information was not correct. The distance to the aerodrome from KK NDB is 3 NM, and the AFIS operator has no explanation to this mistake (he knew the distance was 3 NM). From the correspondence between BGKK AFIS and YN-BZF this department has evaluated the importance of this erroneous information in relation to the possibility of finding the aerodrome under the prevailing conditions.
If the crew had interpreted the distance to the aerodrome to be 10 nm north of the beacon, it would have brought the aircraft into an area with mountain peaks ranging from 1920 ft to 2806 ft. The crew had the Jeppesen 2 JUL 82 edition of the NDB procedure for Kulusuk. This plate gives a clear indication of the relation between the aerodrome and the NDB, and at the edge of the plate scale distance is printed with 1 NM and 5 NM intervals. (Appendix C).

From the radio transmissions can be determined that the distance in question was not later referred to in any way, and from the interviews with the crew the difference from 3 NM to 10 NM was never an issue.
Had the crew planned to make a wide turn when visual below from 291° to 111° to take into consideration the radius of the arc to be 5 NM, the turn should at the speed of 140 kts applied have been executed with a bank angle of about 3.2 degrees only, with a rate of turn of about 0.4 degrees/sec. to aim at a point corresponding to the aerodrome being 10 NM north of the KK NDB. The corresponding figures for the actual radius of an arc of 1.5 NM would be about 11 degrees of bank and a rate of turn of about 1.5 degrees/sec.
It could be expected that a turn into the aerodrome with no prior exact calculation would be made with at least 10 degrees, or even with a "rate one turn" (3 degrees/sec.) as normally applied in an approach procedure. (The captain has later explained that the turn was performed as a "rate one turn" with a bank angle of

* The entire radio correspondence between YN-BZF and AFIS BGKK is depicted in Appendix B.

about 20 degrees). This would bring the aircraft to the coast of the island but a little to the south of the aerodrome. This probably corresponds with the experience gained when aircraft fly into the aerodrome, and this is supported by the radio transmission from the AFIS operator at 2007 hours, which was in accordance with the written procedures for AFIS operators (para. 1.17.1.): "I say again, when visual turn right heading one one one degrees magnetic you will find the aerodrome in front of you or a little to the left, go ahead".

Considering the above discussion and the entire radio correspondence between BGKK and YN-BZF, it is reasonable to conclude that the erroneous distance stated did not have influence on the crew's possibilities of locating the aerodrome.
The weather conditions are believed to have been the main factor in the failure to locate the aerodrome.

However, the possibility exists that the direct bearing requested by the crew of YN-BZF could have been a help in locating the aerodrome, but this bearing was not given by the AFIS operator when it was requested. In accordance with the procedures (reference para. 1.17.1.) this information can be given as follows: "At the earliest possible opportunity and before the aircraft leaves KULUSUK holding at the latest, the following information is given:
Frequency for KK NDB is 283 KHZ - the aerodrome is situated 3 NM from KK NDB in bearing 035° mag. runway in use ....., aerodrome elevation 112 feet."
At 2005 hours the crew requested the bearing from KK NDB to the runway, but as the transmission seemed "hard to read", there may have been a misunderstanding as the AFIS operator gave the outbound bearing for the let-down, but as the request was repeated at 2006 hours the AFIS operator answered "negative .....".
The information should have been passed to the crew, but as it can been seen from the radio correspondence (2023 hours, 2024 hours, 2038 hours) the AFIS operator was reluctant to pass this information, as he assumed that the crew intended to fly directly from the KK NDB over the high terrain to the aerodrome. This department concludes that this was what the crew intended (Appendix B, 2023 - 2033 hours). The AFIS operator's reaction is understandable as an accident which occurred in the area in 1978 (report AIG/06/81), in which the aircraft hit a mountain west of the aerodrome, encompassed the same problem area. Following this accident recommendations were made on let-down procedures, and procedures to be used by AFIS operators.

The weather conditions were varying and an attempt to reach the aerodrome directly from the KK NDB would be hazardous.
Subsequently the AFIS operator had a dialogue with the crew as to the area between the KK NDB and the position of the aerodrome, and advised the crew to fly clockwise round the island (2024 hours), and repeated the last part of the cloud penetration procedure to the crew (2024 hours and 2039 hours).

Although the exact bearing from the KK NDB was never stated to the crew of YN-BZF the information given by the AFIS operator, the transmissions sent by the crew of YN-BZF, and the availability of the let-down plate in the cockpit make the impression that the location of the aerodrome was fairly well established, but that the weather was the overruling factor which made attempts unsuccessful.

Considering the difficulties - as in this accident and in prior cases - in finding the aerodrome at BGKK, this department must conclude that locating the aerodrome at normal authorized weather minima most probably will present problems for crews which are not familiar with the area.
If an aircraft in distress has no other option than to attempt landing at BGKK, and in addition weather conditions are below prescribed minima, the task of attempting landing without guidance by electronic means may be very hazardous.
It is believed that a procedure based on a locator, which gives an inbound track, would present a great improvement for let-downs into BGKK.
This department recommends on the subject.

As seemingly YN-BZF could not find the aerodrome, and the endurance of the aircraft was informed to be 1 1/2 hours (2031 hours) the crew of YN-BZF was at 2044 hours advised of the possibility of attempting a landing at the radar station "SOB STORY" about 168 nm west of BGKK.

The captain acknowledged this information, contacted "BIG GUN" and climbed out towards "SOB STORY" under guidance of "BIG GUN" (2051 hours).
The situation was now considered and treated as an emergency situation by Søndre Strømfjord FIC (2051 hours).

2.4. The accident

"BIG GUN" advised YN-BZF of the minimum safe altitude of flight level (FL) 110 for the area to be overflown.
YN-BZF was informed of relevant data, such as weather conditions at "SOB STORY", runway conditions (snow surface) and length. In the recorded material (CVR) an approximate ground level of the planned landing site is mentioned, when "SOB STORY" in a transmission informs: "You are still landing on the ice, it's all packed ice you are landing on about 9000 ft, over". This department believes that this information refers to the approximate altitude of the site (8241 ft) rather than to the runway length (6000 ft plus 5000 ft overrun) - which had been transmitted to the crew at an earlier stage (para. 1.11.3.). This information was probably not picked up by the crew as the descent was continued below this altitude. From available data and interviews this department is of the opinion that the crew was not very familiar with the conditions of the area to be overflown. During the interview, however, the navigator did seem to have had an idea of

terrain heights in the area. At 2113 hours the endurance was stated to be 30 minutes, and on question from "SOB STORY", the crew declared an emergency.

YN-BZF was flying under IMC, and when the fuel counters indicated low contents the captain decided to start a slow descent in order to get visual ground contact in case the engines should stop due to fuel exhaustion.
During the descent, which must have been slow, the aircraft contacted the snow-coat. Even if there was some vertical visibility to the Icecap, the crew would not and did not, due to the "white out" conditions, realize any snow-coat before the collision. The snow-coat was level with no perceivable contrasts and there was no visible horizon. Furthermore the right hand forward window was covered with ice due to a deficiency in the heating element, making forward visibility impossible for the navigator, who occupied the right hand seat.
The first series of contacts with the snow-coat caused minor break-up, which resulted in an explosive decompression of the cabin (pressure differential was approximately 2 psi). Subsequent contacts caused further damage to the aircraft structure, which finally resulted in loss of control and final disintegration of the aircraft as described in para. 1.12.
At the time of the collision the remaining fuel amounted to approximately 165 kg, and approximately 400 US gal in the auxiliary ferry fuel tanks.
The altimeter at the captain's position was correctly set and indicated the correct height of the terrain at the accident site.

2.5. Survival aspects

Due to a slow descent and the quality of the snow-coat (very soft) the disintegration of the aircraft was not uniform. The front part of the fuselage - the cockpit area - was broken away from the rest of the aircraft, and sufficient structure integrity was maintained in respect to survivability of personnel occupying the area. The members of the aircrew who applied the safety harness were subject to forces within the tolerance of human survivability.

Unfortunately, the immobility of the survivors, apart from the navigator, made conditions for physical survival measures difficult. Luggage and equipment were spread and partly burried in the snow some distance away from the cockpit section, which made it difficult to find equipment that could be used for protection against the cold.
No doubt the survivors were in a state of shock, and no efforts were made to prepare any SOS activity in order to attract rescue personnel. It was known to the crew that rescue aircraft were

alerted and this knowledge either refrained the crew from taking further steps to prepare any action, or the conditions at the site and the dispersion of the wreckage did not offer the possibilities. Also the cold and the light clothing of the crew were factors that severely influenced the possibilities of action.

2.6. Search and Rescue

The measures for preparing Search and Rescue were in accordance with the procedures, and by foresight in the development of the situation the Search and Rescue was activated immediately after the accident had occurred.
The only Search and Rescue facilities that were immediately available were C-130 aircraft from BGSF. Flying time to the area was about one hour, and the wreckage was located 2 hours after the accident had occurred. However, the light conditions were influenced by the twilight coming to an end about 15 minutes after the first sight of the wreckage. Due to approaching darkness and the weather conditions, the area was not clearly visible, and the snow and terrain conditions could not be evaluated, which made it impossible for the crew of the C-130 rescue aircraft to perform a landing.

No survivors were detected, and no visual means that could have indicated survivors at the wreckage were visible. Even with this lack of knowledge of possible survivors the rescue efforts could not be terminated until proof had been established. Therefore other possibilities were contemplated. Due to conditions of weather, light and the remote position of the wreckage the most relevant action to be taken was evaluated to be to return to the site by C-130 aircraft at first light.
The captain of the C-130 decided not to drop a survival package due to the darkness. This decision shall not be questioned by this department.

2.7. The investigation

The chief inspector of air accidents investigation decided that the investigation into the technical aspects of the wreckage was to be limited to the on site investigations already undertaken on the 24th and 25th April 1985. The reasons for this decision were among others:

- Sufficient facts were available to establish the cause of the collision with the snow coat of the Icecap.
- The design of the aircraft type and normal operating systems were not factors in this accident.
- The auxiliary ferry fuel system installed could not be clearly described. The Fokker manufacturer has not been involved in the installation of the ferry fuel tank system used on the subject flight.

- The cost aspects of attempting to retrieve further information from escavation and recovery of the wreckage were out of proportion with the investigative value.

3. **CONCLUSIONS**

a. The crew was properly certified for the flight.

b. According to the crew the normal aircraft systems, except for the FDR and the cockpit right front window electrical deicing system, were functioning normally, which was also determined by the on site investigation.

c. The auxiliary ferry fuel system was not functioning properly. The cause of this has not been conclusively established.

d. The crew did not undertake a satisfactory functional airborne check of the auxiliary ferry fuel system to ensure that it worked prior to the essential appliance of the system for flight. (cause-factor)

e. It is the opinion of this department from the evidence available that a deficiency in the procedures applied for operating the auxiliary ferry fuel system may have been a major factor.

f. The assistance rendered to the flight of YN-BZF was active and generally professional. However, the AFIS operator erroneously stated the distance from the KK NDB of 3 NM to be 10 NM. Furthermore the bearing from the KK NDB was not stated by the AFIS operator at BGKK on request from the crew of YN-BZF.
In the opinion of this department the lack of this information does not seem to have had any important bearing on the possibility of locating the aerodrome.

g. Weather conditions were a major factor in this accident, at the time of the approach into BGKK, as well as at the accident site. (cause-factor)

h. The Search and Rescue operation was anticipated at an early stage and put into effect immediately after the aircraft was considered to have had an accident.

i. The conditions offered on the accident site: low visibility, approaching darkness, and consequently the inability to evaluate surface conditions, precluded successful rescue in the first attempt.

4. **RECOMMENDATIONS**

It is the opinion of this department that better means for let-down to and location of the Kulusuk aerodrome (BGKK) should be offered in order to improve the safety of aircraft flying into the aerodrome. A let-down procedure should be worked out, based on an electronic installation which indicates a direct inbound approach course to the aerodrome.

The Department of Accident Investigation recommends that:

"the Ministry of Greenland prompts the installation of a locator at a position close to the Kulusuk aerodrome (BGKK) which makes it possible to publish a procedure for which the inbound approach heading to the aerodrome is based on an electronic signal." (REC-02-87).

ICAO Note.— Appendices were not reproduced.

ICAO Ref.: 084/85

No. 4

Boeing 747-237B, VT-EFO, accident over the Atlantic Ocean, on 23 June 1985. Report released by the investigating Court, India

SYNOPSIS

1.1.1 On the morning of 23rd June, 1985 Air India's Boeing 747 aircraft VT-EFO (Kanishka) was on a scheduled passager flight (AI-182) from Montreal and was proceeding to London enroute to Delhi and Bombay. It was being monitored at Shannon on the Radar Scope. At about 0714 GMT it suddenly disappeared from the Radar Scope and the aircraft, which had been flying at an altitude of approximately 31,000 feet, plunged into the Atlantic Ocean off the south-west coast of Ireland at position latitude 51° 3.6'N and longitude 12° 49'W. This was one of the worst air disasters wherein all the 307 passengers plus 22 crew members perished.

2.1 **Flight Preparation**

2.1.1. Air India Boeing 747 aircraft VT-EFO 'Kanishka' was operating flight AI-181 (Bombay-Delhi-Frankfurt-Toronto-Montreal) on 22nd June, 1985. From Montreal it becomes AI-182 from Mirabel to Heathrow Airport, London enroute to Delhi and Bombay. The aircraft arrived at Toronto from Frankfurt at 1830 Z and was parked at gate No. 107 Terminal 2 at L.N. Pearson International Airport. In accordance with the Canadian regulations, all the passengers and their baggage were off loaded to complete the customs and immigration checks. Transit cards were handed out to 68 transit passengers destined to Montreal who disembarked at Toronto for customs and immigration checks.

ICAO Note.— Chapter 1 (Preamble) was not reproduced.

2.1.2. The flight from Toronto to Montreal was made up of the following:-

(i) Passengers originating at Toronto and their baggage.

(ii) Transit passengers, and their baggage, continuing their flight to Montreal.

(iii) Two diplomatic bags from Indian Consulate General, Vancouver via Air Canada Cargo Flight, and some Air India Mail.

(iv) Fifth Pod engine and its associated parts.

(v) Interline passengers and their baggage from connecting flights as detailed below:-

a)	Air Canada flight AC-102 from Sasktoon	-	2 Passengers
b)	Air Canada flight AC-106 from Edmonton	-	4 Passengers
c)	Air Canada flight AC-170 from Winnipeg	-	1 Passenger
d)	Air Canada flight AC-170 from Winnipeg	-	4 Passengers
e)	Air Canada flight AC-136 from Vancouver	-	10 Passengers

2.1.3. One passenger by name 'M. Singh', checked in at Vancouver on Canadian Pacific flight CP-060 (Vancouver-Toronto) of 22nd June 1985, and got his one piece of baggage interlined to Air India flight AI-181 even though he had no confirmed reservation on AI-181. This passenger, however, did not board the flight CP-060 at Vancouver and also did not check-in for Air India flight AI-181/182 at Toronto.

2.1.4 The checking-in of passengers for Air India flight AI-181/182 at Toronto began at 1830 Z. The checking-in of the passengers was carried out by Air Canada personnel who are the handling agents for Air India, and was supervised by Air India personnel. The Air Canada personnel indicated the computer sequential numbers (security numbers) on the passenger boarding card stubs. At about 1930 Z announcement was made for the primary security check of passengers and their hand baggage. The passengers passed through the Door Frame Metal Detector and their hand baggage was checked through X-Ray machine. The passengers were also subjected to physical security check with the help of Hand Held Metal Detectors. The transit passengers to Montreal and their hand baggage were also subjected to these security checks, while their checked in baggage, after clearance by the Canadian Customers authorities was placed by the passengers themselves on the conveyor belt while they were still in sterile area. In this way there was personal identification by the passengers of all checked in baggage, except the baggage which had been interlined to this flight.

2.1.5 The flight was closed for check-in at about 2150 Z. There were 10 'NO SHOWS' and 4 'GO SHOWS'. The security checked passengers remained in the holding area gate No. 107 till boarding was announced at about 2210 Z. At the boarding gate secondary security check of the passengers and their hand baggages was carried out. The passengers were frisked with the help of Hand Held Metal Detectors and their hand baggages were opened and physically checked.

2.1.6 The security numbers on the stubs were circled on the pre-numbered Security Control Sheet to ensure that all the checked-in passengers had boarded the aircraft. Passenger boarding was completed by 2300 Z. Traffic/Sales representative of Air India verified the Security Control Sheet with the number of stubs collected and the number of passengers checked-in. He found that all the 202 passengers, who had checked-in, had boarded the aircraft.

2.1.7 As stated earlier, 68 transit passengers had disembarked at Toronto for completing the customs and immigration checks. However, only 65 of these passengers re-boarded the aircraft as per transit cards collected at the boarding gate. It is in evidence that almost every flight of Air India to Canada, two or three transit passengers do not re-board the flight at Toronto. Some Toronto passengers travelling to India buy their tickets "Montreal-India-Montreal"instead of "Toronto-India-Toronto", for which the fare is higher, and they travel by bus to Montreal to catch the Air India flight to India. On their return journey,when they get down at Toronto for customs and immigration checks,they simply do not re-board the flight even though their reservations are upto Montrteal. These passengers sometimes inform Air India personnel at Toronto about their not re-boarding the aircraft. On 22nd June,1985, however, no such passenger informed Air India personnel.

2.1.8 There was a crew change at Toronto. The flight and cabin crew members who took over the flight AI-181/182 had been laid over in Toronto for the week prior to the accident flight and were scheduled to take the flight upto London where they were to be relieved by another set of crew. Capt * was the Commander of the flight, with Capt as co-pilot and Mr. as the Flight Engineer. In addition there were 19 cabin crew members. All the crew members reported together at the airport at 2130 Z. As per the practice existing at that time, the flight crew and cabin crew members were not subjected to frisking checks and their hand baggage were also not security checked. Their checked-in baggage was, however, security checked along with the other checked-in baggage of passengers.

2.1.9 The interline baggage was brought to the international baggage make-up area by the Air Canada staff but, as mentioned earlier, it was not personally identified and matched with the passengers.

2.1.10 The checked-in baggage of the originating passengers and crew members of AI-181/182 was sent on a conveyer belt to the baggage make-up area. All the checked-in baggage along with the interline baggage was required to be security checked on the X-ray machine which was located in the baggage make-up area at the end of international belt No.4.

2.1.11 It has been reported that the X-ray machine worked intermittently for some period and at about 2045Z it broke down and there was no picture on the screen. The machine could not be repaired on that day as it was a week-end and no technician could be contacted. Air India's Security Officer then advised that the rest of the baggage be checked with a PD-4 explosive detector provided by him. He also demonstrated the use of the PD-4 detec- tor to the concerned personnel. It has been reported that about 60 to 70 baggages were checked and cleared by the PD-4 detector.

2.1.12 The security checked baggage was loaded in the containers by the Air Canada personnel. The loading of the baggage in containers

**ICAO Note.*— Names of personnel were deleted.

was over by about 2230 Z. The ramp personnel of Air Canada carried the container and loaded them in the aircraft.

2.1.13 From March, 1985, after the introduction of Air India flight AI-181 through Toronto, diplomatic bags from Indian Consulate General at Vancouver were being sent to India by Air India flight from Toronto. Accordingly, two diplomatic bags, duly sealed and escorted, were delivered to Air Canada office at Vancouver on 21st June and they arrived at Toronto by Air Canada flight AC-580. One of the bags Sl.No. 49 contained 13 empty large diplomatic bags while the other bag Sl.No.50 contained diplomatic mail. The total weight of the bags was 13.8 Kgs.

2.1.14 In addition to the above, a few envelopes containing some flight documents addressed to Accounts Office, Air India, Bombay, and one envelope addressed to Commercial Headquarters, Air India, Bombay from Air India Town Office in Toronto, were collected by Messrs Mega International.

2.1.15 The aircraft was refueled by CAFAS with 14,602 litres of fuel.

2.1.16 On 8th June No. 1 engine of Air India Boeing 747 aircraft VT-EGC had failed during take off. The failed engine was to be ferried to Bombay on flight AI-181/182 of 22nd June.

2.1.17 The failed engine and the associated parts were placed in Air Canada Engineering Hangar at Toronto airport since June 8, when the aircraft was brought to the engineering hangar for engine replacement. Air India had requested Air Canada on 15th June for preparing the failed engine for installation as fifth pod mounting of the aircraft on 22nd June.

2.1.18 On 15th June Air India deputed one of their foremen to Toronto to bring back the failed engine. From 17th to 21st June, Air Canada technicians prepared the failed engine for installation as fifth pod. This preparation involved removal of cowlings, fan blades, locking of compressor rotors etc. Air Canada Engineering/Maintence personnel loaded the aircraft/engine parts on 4 pallets and one container. These pallets and container were then delivered at 0100 Z on 22nd June by Air Canada personnel to Messrs Mega International cargo warehouse at Toronto Airport within restricted airport area.

(Messrs Mega International is the cargo handling agent of Air India at Toronto). The fifth pod engine was transported by Air Canada directly from their premises to the 'Kanishka' aircraft for mounting it on the fifth pod.

2.1.19 Installation of the engine on the fifth pod began immediately on arrival of flight AI-181 at Toronto on 22nd June and the work was completed by 1930 Z. One of the mechanics of Air Canada installed the Mach Air Speed Warning Switch in the Main Equipment Centre as part of the fifth pod engine installation.

2.1.20 The pre-loaded four pallets and one container were brought to the aircraft by M/s Mega International personnel from their warehouse in the afternoon of 22nd June for loading them into the aircraft cargo compartment at positions assigned by the Air Canada load agent. Difficulty was experienced while loading one of the pallets having inlet cowl of the pod engine. To enable loading of the cowl, Air Canada engineering/maintenance personnel removed door stop fitting from the aft cargo compartment door cut-out. After removal of the fittings, the cowl could be loaded. All the removed fittings were then reinstalled.

2.1.21. On account of the delay in loading the cowls, departure of the flight was delayed by one hour and twentyfive minutes.

2.1.22 Maintenance Manager of Air India, Montreal carried out the Terminal Transit Check 'E' of the aircraft and no snag was observed by him. The commander duly accepted the aircraft.

2.1.23 Senior Flight Despatcher, Air India, Toronto did the flight despatch of AI-181/182 for sectors Toronto-Montreal-London. He briefed the flight crew members about flight plan, weather, Air Traffic Control and fuel requirements. The flight plans for the sectors Toronto-Montreal-London were duly accepted and signed by the Commander.

2.2 Progress of the Flight

2.2.1. The aircraft took off from Toronto Runway 24L at 0016 Z on 23rd June, 1985. The Maintenance Manager, Security Officer and Passenger Service Supervisor of Air India travelled on board the aircraft for their duties at Montreal. In all there were 270 passengers on board in addition to 22 crew members.

2.2.2. The route from Toironto to Montreal was V-98/JHL-594/MSS/V 203/FRANX at flight level 290. The flight was uneventful and the aircraft landed at Montreal at 0110 Z. No snag was reported by the flight crew. The aircraft was parked at Cluster 1 Bay No.114.

2.2.3 Sixtyfive passengers destined to Montreal along with the three Air India personnel mentioned above deplaned at Montreal. The remaining 202 passengers, who had joined the flight at Toronto, remained on board the aircraft as transit passengers were not allowed to disembark at Montreal.

2.2.4 Baggage handlers off loaded three containers of baggage, one valuable container and four cargo containers from the aircraft.

2.2.5 Transit Check 'C' of the aircraft was carried out at Montreal. The Flight Engineer also carried out his pre-flight inspection and found that rear latch handle of the fifth pod engine fan cowl was loose. He informed the same to an Air Canada Technician who flaired the handle and applied the high speed tape. There was no other snag observed during the inspection. The personnel of CAFAS refueled the aircraft with 96,000 litres of fuel. Total fuel on board at the time of take off from Montreal was 104,000 Kgs. which was adequate for 8 hours 40 minutes of flying. The commander accepted the aircraft and signed the 'Certificate of Acceptance' of the aircraft.

2.2.6 At approximately 2130 Z Air Canada personnel opened the passenger check-in counter for flight AI-182 (The flight AI-181 terminates at Montreal and the flight from Montreal to London-Delhi-Bombay is designated as AI-182). The checked-in baggage was sent to the baggage make-up area. Between 2300-2350 Z, a suspect suitcase was identified as the X-Ray showed what appeared to be some wires next to the suitcase opening. The suitcase was placed on the floor next to the X-Ray machine. Subsequently two more suspect suitcases were located. These suitcases were also placed next to the X-Ray machine to await the arrival of the Air India Security Officer who was to arrive on Air India flight AI-181 from Toronto. The remainder of the checked-in baggage, which cleared the security check, was loaded in containers by Air Canada personnel for loading on board the aircraft.

2.2.7 Two diplomatic pouches from the Indian High Commission, Ottawa were brought to Mirabel. After the flight arrived; one of the pouches of Category 'A' weighing 1 Kg. was given to the Flight Purser. The other Category 'B' pouch weighing 9 Kgs. was placed in a valuable container 14R.

2.2.8 No other cargo was accepted for this flight except a small package (weighing less than 1 Kg) containing medicines for cancer treatment of a patient in New Delhi. This parcel was received at 1530 Z on 21st June and was loaded in container 14R by Messrs Mega International on 22nd June, more than 24 hours after its receipt.

2.2.9 Five baggage containers, one valuables container and two empty containers were loaded in the aircraft.

2.2.10 The checked-in passengers with their hand baggage went to the departure sterile area. At the entrance to the departure sterile area security staff used X-Ray units and metal detectors to check passengers and their hand baggages.

2.2.11. At approximately 0100 Z, 23rd June, after the primary security check was completed, the passengers proceeded to boarding gate No.80. At this lcoation the secondary security check was done on passengers using hand held metal detectors. Hand baggages were also subjected to further physical and visual check by them.

2.2.12. A total of 105 passengers boarded the flight AI-182 at Mirabel Airport. It was determined that all the passengers who had checked-in, boarded the aircraft. There was no interline passenger. At Montreal there were five 'NO SHOWS' and two 'GO SHOWS'. In all 307 passengers were on board the aircraft. The flight plan and the load and trim sheet, however, indicated 303 passengers as four of the 6 infants were not included in the passenger list.

2.2.13. The seating distribution of the passengers was as given below:-

Zone/Class	Total number of seats	Seats Occupied
Zone 'A' -First Class	16	1
Zone 'B'- Club Class	22	-
Upper deck - Club class	18	7
Zone 'C' - Economy Class	112	104 + 2
Zone 'D' - Economy Class	86	84 + 1
Zone 'E' - Economy Class	123	105 + 3
	377	301 + 6 (Infants)

2.2.14 The seating distribution of the 19 cabin crew members was as follows:-

Two at door L1 and two at door R1
Two at door L2 and two at door R2
Two at door L3 and one at door R3
Two at door L4 and one at door R4
One at door L5 and one at door R5
One in crew rest area, Zone 'A'
One in jump seat upper deck
One crew rest area upper deck.

2.2.15 The three suspected suit cases were not loaded on the aircraft and were detained in the baggage make-up room. After the names of the passengers to whom the suit cases had belonged had been identified the same were transferred to the decompression chamber of an Airline where they were examined, with the aid of a Police Explosive Dog, with negative results. The suit cases were kept overnight in the said chamber and when they were opened it was found that they contained no explosive items.

2.2.16. No unclaimed baggage pertaining to the Air India flight was recovered either at Toronto or at Mirabel or Dorval Airport in Montreal.

2.2.17. The flight plan for the sector Montreal to London was filed on telephone by the Air India Flight despatch from Toronto to Dorval ATC Centre. He requested for route SHERBROOKE-COLOR-NAT XRAY-BUNTY-MERLY-EXMOR-IBLEY-SAMTN-HAZEL-OCKHAM-LONDON at flight level 290 upto COLOR and flight level 330 thereafter. The reporting points on Track XRAY on that day were COLOR, 47N/50W, 49N/40W,50N/30W, 51N/20W, 51N/15W, 51N/08W and BUNTY.

2.2.18 The aircraft took off from Montreal at 0218 Z. Its estimated time of arrival at London was 0833 Z. The CVR and the ATC tapes show that the flight was normal and quite uneventful. Suddenly at about 0714 Z, when the flight was being monitored by the Air Traffic Controller at Shannon, with the help of secondary surveillance radar, the aircraft disappeared from the radar scope. Subsequently, the ATC at Shannon got to know that the aircraft had met with an accident and its wreckage was sighted about 110 miles west south-west of Cork, Ireland.

PERSONNEL INFORMATION

2.3.1 Pilot-in-Command

2.3.1.1 Capt. (age 561/2 years, date of birth 25th November, 1928) joined Air India on 1st October, 1956. He held ALTP Licence No. 247 valid upto 29th October, 1985 and FRTO No. 478 valid upto 23rd October, 1985. He was released as a Co-pilot on Boeing 707 aircraft on 21st July, 1960 and as a Commander on Boeing 707 aircraft on 17th September, 1964.

2.3.1.2 For conversion as Pilot-in-Command on Boeing 747 aircraft, Capt. had undergone ground training at Boeing Airplane Company, USA and simulator and aircraft flying training at Bombay in 1972. He completed his route checks for Pilot-in-Command endorsement between December, 72 and January, 73. He became a Commander on Boeing 747 aircraft on 14th February, 1973.

2.3.1.3 Details of Capt's. flying experience and licence renewal checks are as given below :

a. Total flying experience : 20, 379:15 hours

b. Flying experience on B-747 as
   - (i) Pilot-in-Command : 6,364.50 hours
   - (ii) Co-pilot : 123:45 hours

c. Day flying experience on B-747 aircraft : 3,980:00 hours

d. Night flying experience on B-747 aircraft : 2,508:35 hours

e. Flying experience during
   - (i) last 6 months : 301:45 hours
   - (ii) last 3 months : 159:40 hours
   - (iii) last 30 days : 68:45 hours
   - (iv) last 7 days : 9:00 hours

   He had last flown as Pilot-in-Command on flight AI 181 (Frankfurt to Toronto) on 15th June, 1985.

f. Date of last licence renewal and IR check : 8 May, 1985

g. Date of last route check : 24 March, 1985

h. Date of last medical examination at CME, Delhi : 29 April, 1985

i. Date of last simulator refresher course : 19 December, 1984

j. Date of ground technical refresher course : 6/7 May, 1985

k. Date of last flight safety refresher course : 25 July, 1984

1. Rest period before operating the accident flight : 1 week

2.3.1.4 Records indicate that on 29th June, 1966, Captain was declared medically unfit for 2 months to reduce his weight by 10 lbs. In February, 1973 he was advised to wear corrective by-focal glasses while flying. In May, 1975 he was again declared medically unfit for 3 months.

2.3.1.5 Capt. was earlier involved in the following two incidents :

(a) On 25th August, 1984, while operating flight AI-1100 from London to Delhi, there was a deviation of the aircraft by about 170 nautical miles from the track over Rahimyar Khan in Pakistan. He was given necessary INS refresher and route checks with particular emphasis on cross checking procedure.

(b) On 6th December, 1984, while operating flight AI-124 Delhi-Bombay, the aircraft was observed approaching runway 32 at Bombay Airport when runway in use was 27. Captain was given simulator training for a series of approaches and landings and visual circuits from right hand and left hands seats for approaches and landings on runway 27 at Bombay Airport.

2.3.1.6 Captain was not involved in any accident previously.

2.3.2 Co-pilot

2.3.2.1 Capt. (age 41 1/2 years, date of birth 30th November, 1943) joined Air India on 12th October, 1977. He held ALTP Licence No. 940 valid upto 25th July, 1985 and FRTO Licence No. 2290 valid upto 2nd February, 1986.

2.3.2.2 Capt. was released as a Co-pilot on Boeing 707 aircraft on 18th November, 1978 and as a Co-pilot on Boeing 747 aircraft on 17th May, 1980.

2.3.2.3 Details of his flying experience and licence renewal checks are as given below :

a.	Total flying experience	:	7,489:00 hours
b.	Experience on B-747 aircraft as Co-pilot	:	2,469:30 hours
c.	Day flying experience on B-747 aircraft	:	1,426:15 hours
d.	Night flying experience on B-747 aircraft	:	1,043:15 hours
e.	Flying experience during		
(i)	last 6 months	:	157:45 hours
(ii)	last 3 months	:	65:00 hours
(iii)	last 30 days	:	20:15 hours
(iv)	last 7 days	:	9:00 hours
	He had last flown as Co-pilot on flight AI-181 (Frankfurt to Toronto) on 15th June, 1985).		
f.	Date of last licence renewal check	:	25th March, 1985
g.	Date of last IR check	:	23rd November, 1984
h.	Date of last route check	:	9 April, 1985
i.	Date of last medical examination at CME Delhi	:	14 January, 1985
j.	Date of last simulator refresher course	:	16 July, 1984
k.	Date of last ground technical refresher course	:	8/9 October, 1984
l.	Date of last flight safety refresher course	:	3 December, 1984
m.	Rest period before operating the accident flight	:	1 week.

2.3.2.4 Records indicate that Capt. was not involved in any accident earlier.

2.3.3 Flight Engineer

2.3.3.1 Flight Engineer Mr. (age 57 1/2 years, date of birth 10th October, 1927) joined Air India on 27th December 1954. He held flight Engineer's Licence No. 37 valid upto 6th December, 1985. Mr. was released as a Flight Engineer on Boeing 707 airecraft on 16th December, 1963 and on Boeing 747 aircraft on 6th February, 1974. He had a total flying experience of 14,885 hours out of which 5,512:35 hours were on Boeing 747 aircraft.

2.3.3.2 Last medical examination of Mr. was completed on 1st October, 1984 at CME Delhi. He had completed simulator refresher course on 14th February, 1985, ground technical refresher course on 14/15th January, 1985 and flight safety refresher course on 13th August, 1984.

2.3.4 Cabin Crew

2.3.4.1 A total of 19 cabin crew members were on duty on Flight AI-181/182 on 23rd June, 1985. Their brief details are as given below :

Sl.No.	Names	Designation	Flight Safety course completed on
1.		Inflight Supervisor	1/2 April, 1985
2.		Flight Purser	18 February, 1985
3.		Flight Purser	9/10 May, 1984
4.		Flight Purser	23 January, 1985
5.		Flight Purser	15 January, 1985
6.		Asst. Flight Purser	2/3 May, 1985
7.		Asst. Flight Purser	3 December, 1984
8.		Asst. Flight Purser	12/13 Sept., 1984
9.		Asst. Flight Purser	17/18 Dec., 1984
10.		Asst. Flight Purser	11/12 February, 1985

11.	Airhostess	13 July, 1984
12.	Airhostess	10/11 April, 1985
13.	Airhostess	11/12 February, 1985
14.	Airhostess	17/18 April, 1985
15.	Airhostess	17/18 Dec., 1984
16.	Airhostess	15/16 April, 1985
17.	Airhostess	10/11 June, 1985
18.	Airhostess	3/4 April, 1985
19.	Airhostess	29/30 April, 1985

AIRCRAFT INFORMATION

2.4.1 General

2.4.1.1. Boeing 747-237B 'Kanishka' aircraft VT-EFO was manufactured by Messrs. Boeing Company under Sl.No. 21473. The aircraft was acquired by Air India on 19th June, 1978. Initially, it came with the expert Certificate of Airworthiness No. E-161805. Subsequently, the Certificate of Airworthiness No. 1708 was issued by the Director General of Civil Aviation, India on 5th July, 1978. The C of A was renewed periodically and was valid upto 29th June, 1985. From the beginning of June, 1985, C of A renewal work of the aircraft was in progress. The aircraft had the Certificate of Registration No. 2179 issued by the DGCA on 5th May, 1978. The commercial flight of 'Kanishka' aircraft started on 7th July, 1978.

2.4.1.2 The aircraft was maintained by Air India following the approved maintenance schedules. It had logged 23634:49 hours and had completed 7525 cycles till the time of accident.

2.4.1.3 The aircraft was fitted with four P & W JT9D-7J engines having thrust rating of 48650 pounds. The hours and cycles logged by the engines since new till the time of accident are as given below :

Engine No.1 : P662927-7J - 29,663:26 Hrs (9422 cycles)
Engine No.2 : P695610-7J - 20,810:28 Hrs (6031 cycles)

Engine No.3 : P695602-7J - 21,992:31 Hrs (6564 cycles)
Engine No.4 : P662926-7J - 32,332:15 Hrs (11295 cycles)

2.4.1.4 All the DGCA mandatory modifications and inspections applicable to the subject aircraft had been compiled with. No major component installed on this aircraft and its engines had exceeded the stipulated life period.

2.4.1.5 The last quarter Periodic Check of the aircraft was carried out on 24th May, 1985, at 23274:53 hours and 7439 cycles. Subsequent to this check, two Check 'B' schedules were carried out. The last Check 'B' was carried out on 17th June, 1985, at 23564:14 hours and 7510 cycles and was valid for 200 flying hours.

2.4.1.6 The aircraft had flown 359:56 hours and 86 cycles since last quarter Periodic Check and 70:35 hours and 15 cycles since last Check 'B' till the time of accident.

2.4.1.7 The last Flight Release Certificate was issued on 24th May, 1985 on completion of quarter Periodic Check and was valid for 1100 hours or 150 days elapsed time whichever occurred first. After the last departure from Bombay on 21st June, 1985, the aircraft had flown for 22:34 hours till the time of crash.

2.4.1.8 Mr. Maintenanace Manager, Air India, Montreal carried out the Terminal Transit Check 'E' of the aircraft at Toronto on 22nd June, 1985 and no snag was observed by him. No snag was reported by the flight crew during the flight from Toronto to Montreal. Transit Check 'C' of the aircraft for the flight AI-182 was carried out at Montreal by Mr. and three Air Canada technicians. The flight engineer also carried out his pre-flight inspection and found that the rear latch handle of the fifth pod engine fan cowl was loose. He informed the same to Mr. Air Canada technician who faired the handle and applied high speed tape. No other snag was observed during the inspection.

2.4.2 Previous Incidents and Snags

2.4.2.1 A maintenance Group was formed with representatives from Air India and Airworthiness Directorate with Mr. Senior Air Safety Officer as the Group Leader to scrutinise the maintenance documents and various defects experienced on this aircraft. The report submitted by the Group (Attachment 'B') indicates that the aircraft was involved in six incidents since the last C of A renewal, details of which are given below

(i) On 13th July, 1984 at Dubai -- flight AI-868

The aircraft returned after aborting take off due to no rise in the EPR and N1 on No.1 engine (Sl.No. 695612). The engine front and rear were checked and found OK. Slight wetness was noticed in the bleed outlets. No external oil leak was noticed. Oil quantity was topped up. The chip detectors and oil filter were found OK. EVC Ph filter was found OK. EVC linkage was exercised. The engine was run up and its operation was found satisfactory. The snag was suspected to be due to lack of pressurising air at low N1.

(ii) On 18th July, 1984 at Delhi -- flight AI-105

The right hand side fuselage skin between stations 480 and 500 in line with lower portion of forward cargo door cut-out was damaged by high lift. The same was repaired at Delhi. Permanent repair was carried out at Bombay. The repairs were accomplished using guidelines given in the Boeing Structural Repair Manual.

(iii) On 12th August, 1984, at Rome -- flight AI-135

The aircraft landed with No. 2 engine (Sl.No. 662826) shut down in flight due to oil pressure and oil quantity droping. On motoring the engine, oil leak was observed from metal line between F C O C and L O P switch at the switch end. The line was found cracked which was welded and refitted. The line was subsequently replaced at Bombay.

(iv) On 24th October, 1984, at London -- flight AI-104

There was total loss of No.1 hydraulic system fluid. The fluid leak was traced to inlet pressure adapter of flap control module in the left hand body gear wheel well. Two of the four bolts holding the adaptor on the flap control module had sheared. The hydraulic pump, seal, back-up ring and case drain filter were replaced. The flap control module was replaced when the aircraft arrived at Bombay.

(v) On 14th February, 1985, at Delhi -- flight AI-164

On arrival the leading edge honey comb of the left hand aft trailing edge flap was found damaged about 18 inches in length due foreign object damage. Necessary repair was carried out at Delhi. The aft flap was replaced at Bombay.

(vi) On 28th May, 1985, at Dubai -- flight AI-103

On arrival, the left hand wing to fuselage botton fairing forward rubber seal with strip was found torn off. Temporary repair was carried out at Dubai. Permanent repair was carried out subsequently at Bombay.

2.4.2.2 The flight snags recorded in the flight report books of the aircraft during the 4 1/2 month period prior to the accident were scrutinised by the Maintenance Group and the only significant repetitive defect observed was "R2 door not going to manual". On ground checks by the aircraft maintenance engineers, the operation of the selector was, however, found normal.

2.4.2.3 Prior to operating the accident flight, the aircraft arrived at Toronto from Frankfurt. Capt. was the commander of the flight. The flight crew had reported the following three snags :

(i) HF system No. 2 had a lot of distortion

(ii) E P R L indicator unserviceable in 'Go around' mode

(iii) Hydraulic system No.1 pressure indication unserviceable (This snag was carried forward from Delhi).

2.4.2.4 The Auxiliary Power Unit (APU) was unserviceable ex-Bombay and had been released under M E L.

2.4.2.5 For rectification of the above stated snag No.1, Air India's Maintenance Engineer at Toronto checked the connections of the transreceiver and reracked the unit. No snag was reported on this system on Toronto-Montreal sector.

2.4.2.6 Snag No. 2 was carried forward.

2.4.2.7 Regarding the third snag, Mr. has stated that the indicator showed 4000 P S I pressure even with no pump running. He therefore, interchanged No.1 and No.3 indicators. The snag, however, persisted. He then replaced transmitter No.1 with a spare transmitter from the aircraft SE box and the snag was rectified. No rectification work was however, recorded by the AME in the Flight Report Book. No snag was reported on this system on Toronto-Montreal sector.

2.4.3 <u>Installation of 5th Pod Engine</u>

2.4.3.1 On 8th June, 1985, No.1 engine of Air India Boeing 747 aircraft VT-EGC operating flight AI-181 failed during take off at Toronto. The aircraft returned and the engine was replaced by a loaned engine from Air Canada. The removed engine was a P & W JT9D-7Q type (Sl.No. P702353-7Q).

2.4.3.2 Air India had planned to bring back the failed engine of VT-EGC aircraft to Bombay, as fifth pod on their flight AI-181/182 of 22/23 June, 1985 and had sent an engineer along with the necessary kit to Toronto on 15th June, 1985. The engine borrowed from Air Canada on 8th June, 1985, was flown back to Toronto as a fifth pod engine on flight AI-181 of 22nd June, to return it to Air Canada.

2.4.3.3 The Controller of Airworthiness, Bombay examined the aspects relating to installation of the 5th Pod engine, loading of its components and certification of the related work. His report indicates that the failed engine and the associated parts were kept in the Air Canada engineering hanger at Toronto airport since June 8 when the aircraft was brought to the hanger for engine replacement. Air India requested Air Canada on 15th June, 1985, for prepairing the failed engine for installation as fifth pod engine on 22nd June. Accordingly, Air Canada's technicians undertook the preparatory work of removing the cowlings, fan blades, panels, locking of compressor, turbine rotors etc. on 17th June, 1985, and completed the work on 21st June, 1985. The fan blades (46 in number) from the failed engine were placed in 12 wooden shipping boxes provided by Air India. These boxes were then loaded in a container. The other components of the failed engine were loaded on 4 pallets.

2.4.3.4 Installation of the fith pod engine was carried out by Air Canada technicians and the individual items on the task card were certified by the individuals who had carried out the work.

2.4.3.5 Some difficulty was experienced while loading one of the pallets having inlet cowl of the pod engine. To enable loading of the cowl, Air Canada engineering/maintenance personnel removed door stop fittings from the aft cargo compartment door cut-out. After removal of the fittings, the pallet could be loaded. All the removed fittings were then re-installed. Removal and installation of the fittings was certified by Mr.

2.4.3.6 A question arose whether removal of the door stop fittings could have caused some difficulty in flight. From the video films of the werckage it was found that the complete aft cargo door was intact and in its position except that it had come adrift slightly. The door was found latched at the bottom. The door was found lying along with the wreckage of the aft portion of the aircraft. This indicates that the door remained in position and did not cause any problem in flight. In the front cargo compartment, there were 16 containers out of which four were empty. Five containers had baggage of Delhi bound passengers. Container at Position 13L had baggage of the first class and London passengers and container at position 13R had crew baggage. The entire baggage of passengers ex-Montreal was loaded in containers at positions 12R, 21R, 22R, 23R and 24R in the front cargo compartment. Container at position 24L contained fan blades in wooden boxes and the other components of the pod engine. Valuable container was at position 14R.

2.4.3.7 In the aft cargo compartment, there were four pallets containing parts of the fifth pod engine and two containers at positions 44L and 44R containing baggage of Delhi bound passengers. The bulk cargo compartment contained passenger baggage bound for Delhi and Bombay. All the baggage and engine parts in the aft and bulk cargo compartments were loaded at Toronto.

2.4.3.8 The total weight of the fifth pod engine and its items was about 9000 kgs. As a result of carriage of the fifth pod engine, the payload of the flight was considerably reduced on London-Delhi sector.

2.4.3.9 At the time of take off from Montreal the aircraft had 104,000 kgs of fuel on board which was adequate for 08:40 hours of flying as against sector flying time of 06:15 hours. The flight plan fuel was calculated taking Paris as the alternate airport for London.

2.4.3.10 The load and trim sheet from the sector Montreal London was prepared and was duly counter-signed by the commander. The take off weight of the aircraft was 317,877 kgs which was within the maximum take off weight limit of 334,500 kgs. The estimated landing weight of the aircraft was 237,177 kgs which was also within the maximum landing weight limit of 256,279 kgs. The centre of gravity of the aircraft was at 21.3 percent of MAC at take off and the estimated C G position at the time of landing at London was 25.8 percent of MAC which was within the limits.

2.4.3.11 The load and trim sheet and the flight plan of the aircraft indicated that there was 301+2 passengers on board the aircraft whereas there were actually 301+6 passengers on board. The error occured because four of the six infants were not taken into account.

2.4.4 Corrosion Control Measures

2.4.4.1 Boeing Company have recommended various measure to control corrosion on Boeing 747 aircraft through different documents such as Maintenance Planning Data Document, Corrosion Prevention Manual and Service Bulletins. Compliance of these measures on Air India fleet is accomplished as follows :

(i) Support structure under galleys and lavatories

Boeing Company have recommended repeat inspections of under galley/toilet structure at intervals of 12000 hours.

However, in order to detect corrosion at an early stage, these inspections are carried out by Air India at intervals not exceeding 9000 hours.

(ii) Fuselage Lower Bilge Area :

Boeing Company have recommended modifications to provide improved drainage systems by incorporation of various Service Bulletins. All the relevant modification have been completed by Air India on the affected aircraft. In addition to completion of these modifications, repeat inspection of lower bilge area is being carried out to meet the requirements of Boeing Service Bulletins.

(iii) Canted Pressure Deck :

In order to prevent water accumulation and consequent corrosion in the area, Boeing Company have issued SBs 51-2015, 51-2026 and 51-2032. Air India have incorporated Service Bulletins 51-2015, and 51-2032 on all their affected airplanes SB 51-2026 is being complied progressively.

(iv) Cargo Compartments :

Inspection of all the cargo compartment interior structures for corrosion and cracks is being accomplished periodically by Air India after removal of linings and insulation blankets.

(v) Aft Pressure Bulkhead :

During every equalised Periodic Check routine, the aft surface of aft pressure bulkhead is being visually inspected for corrosion condition and security of attachments. The forward surface of the pressure bulkhead, which is covered by aft toilets, is inspected after removal of toilets at intervals not exceeding 9000 hours although the recommended interval by Boeing Company is 12000 hours.

2.4.4.2 Air India has stated that in addition to the above specific measures, aircraft structure particularly the areas below toilets, galleys, cargo compartments, outflow valve area etc. which are prone to corrosion, are inspected for corrosion, cleaned and protected during every equalised Periodic Check. Air India have further stated that no serious corrosion problem has been experienced by them so far on their fleet.

2.4.5 Supplemental Structural Inspection Programme

2.4.5.1 In the case of airplanes which have completed 10,000 flight cycles as on June 30, 1983, Federal Aviation Administration (FAA) U S A and Boeing Company had recommended additional structural inspections known as Supplemental Structural Inspection Programme. In the Air India fleet, the first three 747 aircraft, namely, VT-EBE, VT-EBN and VT-EBO fell in this category and are known as 'Candidate Airplanes'. The subject aircraft (VT-EFO) had completed only 7525 flight cycles at the time of the accident on 23rd June, 1985, and therefore, the Supplemental Structural Inspection Programme was not applicable to this aircraft.

2.4.6 Special Corrosion Inspection of B-747 Aircraft Fleet of Air India

2.4.6.1 In order to examine whether corrosion to the aircraft structure of Kanishka aircraft could have contributed to the accident, a group was constituted by Mr. Inspector of Accidents to carry out special corrosion Inspection of all the Boeing 747 aircraft of Air India.

The group consisted of the following members :

(a) Senior Air Safety Officer of the D.G.C.A.
(b) Senior Airworthiness Officer of the D.G.C.A.
(c) Air India's Representative.

2.4.6.2 The inspection was carried out in the following areas :

(a) Below toilets and galleys
(b) Forward and aft cargo compartments belly areas - internally and externally
(c) The forward and aft pressure bulkheads
(d) Canted pressure web area from inside the passenger cabin.
(e) Area around outflow valves
(f) MEC area inside and outside.

2.4.6.3 The inspection reports submitted by the Group show that no corrosion was noticed on the significant primary structural members of the aircraft. Surface corrosion was, however, noticed on some of the members below the toilets and galleys. The corrosion observed during the inspection was of minor nature which is normally expected on such inspection schedule. The Kanishka aircraft was subjected to Periodic Check on 24th May, 1985 at 23,274.53 hours/7,439 cycles and no significant corrosion was observed. Among the Nine 747 aircraft inspected for corrosion, 5 aircraft had logged hours more than the Kanishka aircraft. Three of the aircraft had actually logged nearly double the flying hours. Taking into consideration that the corrosion prevention measures recommended by the Boeing Company were followed by Air India and that even the high life aircraft (45,000 hours approximately) subjected to corrosion inspection at the time when Periodic Check was due i.e. 1100 hours since previous check, had no significant corrosion, it is considered unlikely that Kanishka aircraft, which had logged only 23,275 hours since new and 360 hours since last Periodic Check, had corrosion which could have contributed to the accident.

METEOROLOGICAL INFORMATION

2.5.1 A report on the Meteorological conditions prevailing en-route near the location where the aircraft crashed was provided by the Meteorological Service, Department of Communications, Dublin, Ireland. This report covers a period of one to two hours before and after the time of accident (0714 Z).

2.5.2 From the report it is seen that the surface Synoptic Situation in the vicinity of 51°N, 12.50°W at 0715 Z on 23rd June was as given below :

Surface wind	:	250/15 knots
Surface visibility	:	10 Kms (occasionally 4 kms in drizzle)
Surface temperature	:	13°C
Cloud conditions	:	Cloud cover in the area was estimated to have been layered upto about FL 100 with a base of 600 feet. There is no evidence of cumulonimbus or thunderstorm activity.
Freezing Level	:	700 feet.

2.5.3 With regard to Upper Air situation the report indicates that a mainly West or West North West airflow covered the area of FL 310 The Jet stream was centred at about 48°N. The estimated wind and temperature at FL 310 were 270/65 knots and -47°C. As per the report, at FL 310, 51°N 12.50°W and at 0715 Z any significant clear air turbulence was not expected.

2.5.4 Sunlight condition was prevailing at the time of accident. There were no sigmets valid for the area at that time.

AIDS TO NAVIGATION

2.6.1 The aircraft was equipped with Inertial Navigation System (INS) and was cruising normally at its assigned flight level 310 on track X-ray over Atlantic. It was under the control of Shannon Upper Area Control and was being monitored on the Secondary Surveillance Radar (SSR) located at Mount Gabreal. Till the time of accident, the aircraft was beyond the range of Shannon primary radar.

2.6.2 The aircraft entered Shannon airspace at the correct position and level and remained on the assigned track and flight level till it disappeared from the radar screen.

2.6.3 There is no evidence to indicate that AI-182 experienced any navigational problem during the flight.

COMMUNICATIONS

2.7.1 Two-way communication between the ill-fated aircraft and the ATS units of Canada and Ireland was maintained during the flight from Montreal till the time of crash. The communications were recorded on the ATC tapes. Transcripts of the relevant tapes were provided by the Canadian Aviation Safety Board and the Director of Air Traffic Services, Ireland.

2.7.2 From the Transcript of the conversations, it is observed that two-way communication between AI-182 and the various ATS units was normal. The last R/T contact with the aircraft was at 0709:58 Z when AI-182 informed Shannon UAC that it was squawking 2005. The tape transcript also shows that the aircraft did not transmit any information regarding the emergency on frequency 131.15 MHz on which it was last working with Shannon UAC or on distress frequency 121.5 MHz. Indecipherable noise was, however, found recorded on the Shannon ATC tape just at the time of crash i.e. 0714:01 Z. Thereafter, repeated calls were made by Shannon UAC to AI-182, but there was no response.

SEARCH AND RESCUE

2.8.1 The report of the Search and Rescue Group gives the details of the Search and Rescue operations. From the report it is seen that at 0730 Z, Shannon UAC informed Marine Rescue Co-ordination centre (MRCC) shannon that AI-182, a Boeing 747 aircraft enroute Montreal-London had disappeared from the Secondary Surveillance Radar (SSR) at 0713 Z in position 51N/120W. Shannon UAC requested MRCC Shannon to take emergency section. At 0740 Z MRCC Shannon telephonically explained the situation to Valantia Coast Radio Station (CRS) and requested a PAN Broadcast urgently and to ask any vessels in area to keep sharp lookout and report to Valantia Radio. At 0746 Z Valantia Radio transmitted to all stations PAN message and above advice to ships. The transmission was repeated.

2.8.2 At 0750 Z, an Irish Naval Vessel AISLING reported on R/T to Valantia Radio that it was 54 miles from site of accident and was proceeding to the site. Valantia Radio passed on this information by Telex to MRCC Shannon. Between 0740/ 0750 Z MRCC briefed the Irish Naval Service (INS) Haulbowline, MRCC Swansea, RCC Plymouth and Irish Army Air Corps (IAAC) on the situation. At 0754 Z MRCC relayed a distress message to Shannon Aeradio via the Aeronautical Fixed Telecommunication Network (AFTN).

2.8.3 At 0803 Z Valantia Radio again transmitted the PAN message and the advice to ships. At 0840 Z Cargo vessel M W Laurentian Forest/HBWP (Registered in PANAMA and owned by Federal Commerce of Montreal, Canada) at position 51.09N/12.18W reported that it was 22 miles away from distress area and was proceeding there. Laurantian enquired if there were other ships in the area and was informed about position of Aisling. At 0813 Z Valantia Radio informed MRCC Shannon by telex about Laurentain Forest.

2.8.4 Between 0815/0820 Z, MRCC Shannon updated RCC Plymouth and they advised that a Nimrod rescue aircraft would depart shortly for the area and that SEA KING helicopters were already enroute to Cork Airport initially. Edinburgh RCC advised MRCC Shannon that a Nimrod rescue aircraft was also being prepared at Kinloss. At 0820 Shannon Aeradio informed Valantia Radio that there was message from Shanwick Oceanic Control that aircraft were picking up ELT signal in position 51N/15W and 51N/08W and the actual position was believed to be 51W/1250W. At 0833 Z, Valentia Radio sent message giving the above information and requesting ships in the area to report to Valentia Radio.

2.8.5 At 0842 Z, Ali Baba informed Valentia Radio that it was at position 5125.5N/0825.4W and was listening on 121.5 MHz. At 0850 Z Western Arctic informed Valentia Radio its position 5207N/1151W and that it would proceed in about 20 minutes after bringing in cable. At 0857 Z, High Seas Driller informed Valentia Radio that Vessel Kongstain could be released, ETA 51/2 to 6 hours and they would standby. At 0858 Z, Valentia Radio informed MRCC Shannon about reports from Ali Baba Western Arctic and High Seas Driller.

2.8.6 At 0905 Z, Laurentian forest reported to Valentia Radio that it was 5 miles from SOS position 51N/12.5 W and it had not sighted anything. Between 0905/0908 Z, three more vessels viz. Atlantic Concern, MV Norman Amstel and MV Tasman reported their positions to Valentia Radio. At 0908 Z, Swansea advised MRCC Shannon that four Seaking helicopters and two Nimrod aircraft were enroute.

2.8.7 At 0913 Z, Laurentin Forest reported to Valentia Radio that they had sighted what looked like 2 rafts about 2 miles away. At 0914 Valentia Radio informed MRCC Shannon about the report from Laurentian Forest.

2.8.8 At 0918 Z, Laurentian Forest reported to Valentia Radio that it had sighted wreckage in water at position 5101.9N/1242.5W and the liferafts were not inflated. Valentia Radio passed the message to MRCC Shannon at 0920 and also sent transmission about wreckage sighting. Lifeboats Valentia and Baltimore reported to Valentia Radio that they were proceeding to the position of wreckage.

2.8.9 At 0937 Z, Laurentian Forest reported that it had sighted 3 bodies in water. Valentia Radio informed the same to MRCC Shannon at 0940 Z. At 0945 Z, MRCC Shannon and MRCC Swansea decided that for security and operational reasons Cork Airport would be the primary operational base and ATC Cork were informed of this decision.

2.8.10 At 0953 Z, S MYROLI informed Valentia Radio that it was 80 miles north of position and had a group of 10 to 20 French vessels and desired to know if they should proceed to site. After consulting Laurentian Forest, S MYROLI was advised that it was not necessary. Valentia Radio kept on giving Mayday relay frequently.

2.8.11 At 1045 Z, a prohibited flying area was established with a radius of 40 N Miles from the datum point from sea level to 5000 feet. Falmouth Coast Guard reqested Valentia Radio the position of all ships in the distress area and those proceeding so that each vessel could be designated to search a particular area.

2.8.12 At 1126 Z, Laurentian Forest reported Valentia Radio that it had located numerous bodies in water and Seaking helicopter was hovering there. Valantia Radio transmitted this information to all stations.

2.8.13 At 1133 Z, Valentia Radio informed Coast Guard Falmouth the position and ETA of various ships and also of the lifebouts Valentia and Beltimore. At 1150 Z, RRC Plymouth requested MRCC Shannon that "Le Aisling" assume duty as "On Scene Commander Surface Unit". At 1204 Z, information was received by Valentia Radio that 8 Spannish Trawlers were proceeding to distress position of AI-182 and their ETAs were between 1630/2000 Z. At 1246 Z, Star Orion informed Valentia Radio that it would be able to refuel any vessel in medium or small quantities at the accident site. Valentia Radio informed MRCC Shannon and Falmouth about the Spanish Vessels and Star Orion.

2.8.14 Falmouth requested Valentia Radio at 1303 to advise Laurentian Forest to inform Aisling that 8 Spanish trawlers would arrive in search area between 1600 Z and 2000 Z and Aisling should deploy trawlers in conjunction with lifeboats to recover bodies as it would be easier to recover than from large vessels. Valentia Radio sent the above message.

2.8.15 Laurentian Forest informed Valentia Radio at 1307 Z that 10 bodies were on Aisling, 4 on Helo, and they had some alongside and had launched lifeboats to pick them up. Valentia Radio informed the same to MRCC Shannon and Falmouth. At 1338Z, MRCC Shannon requested Valentia Radio to include the following in their broadcast :

> "Vessels within 100 N Miles of datum 5101.9N/1242.5W are requested to proceed to search area and contact Aisling/EIYP. Any vessels recovering bodies or wreckage are requested to retain them on board and inform MRCC Falmouth of total number of bodies recovered."

2.8.16 Valentia Radio transmitted the above message at 1340 Z to all stations and also informed MRCC Shannon. At 1503 Z Aisling informed Valentia Radio that they had recovered 56 bodies. MRCC Shannon requested Valentia Radio to advise Aisling that if they could locate "Black Box", they should drop buoy. Valentia Radio advised Aisling accordingly. At 1530 Z, on advice from MRCC Shannon, Valentia Radio asked Baltimore, Courtmaesherry and Ballycotton lifeboats to return to base. At 1633 Aisling requested Valentia Radio to inform Falmouth that they were unable to transfer bodies to Valentia lifeboat as latter was returning to base owing to fuel shortage. At 1659, Laurentia Forest informed Valentia Radio that 66 bodies had been picked up by then. Aisling advised Valentia Radio that Valentia lifeboat was returning with four bodies.

2.8.17 At 1721 Z Falmouth requested Valentia Radio to relay following to all surface units at scene :

1. One nimrod remaining on scene overnight.
2. All other air units will be recalled at 2200 Z. One Helo remains at 15 minutes notice at Cork
3. Air Search recommences at 240400 Z.
4. All Civil surface units will be released by 2200 and may proceed on passage. Bodies should be landed at Irish Post for transfer to receiving station at Cork Airport.
5. Warship Challenger, Emer and Aisling acknowledge".

2.8.18 At 1723 Z Aisling informed Valentia Radio that they saw 3 Spanish vessels approaching and they were using Ch.16 which Aisling was using for co-ordination with RESCUE 52 and requested that Spanish vessels be asked to stay outside 5 miles radius. Spanish agent was told about Aisling request.

2.8.19. Valentia lifeboat informed Valentia Radio that they were heading for home (Valentia) at reduced spead of 11 knots and they had five bodies on board. At 1822 Z, Aisling requested Valentia Radio information on 'Black Box' that might help its location. Aisling was advised of ELT signal on 121.5 MHz. At 1840 Z Cork ATC Advised MRCC Shannon that a total of 64 bodies were in Cork.

2.8.20 At 1920 Z, MRCC Shannon downgraded the 'MAYDAY' Broadcast to 'PAN' (Urgency) Broadcast, Aisling informed Valentia Radio that 79 bodies had been recovered. At 1958 Z Laurentian Forest informed Valentia Radio that they were proceeding to Dublin. Valentia Radio thanked them for assistance.

2.8.21 At 2000 Z, MRCC Swansea advised MRCC Shannon that main air search would cease at 2200 Z and would recommence at 240400 Z. The overnight search would continue with one Nimrod providing air cover for the surface search by three warships. Vessels transiting the area were requested to keep a sharp look out and to report to HMS Challenger.

2.8.22 By 0300 Z on 24th June, four Seaking helicopters had departed from Cork to resume the airborne search. At that time the search area covered a six nautical mile radius of position 5059.2 N/1225.3W and the vessels Le Emer and HMS Challenger were requested to search this area. HMS Challenger was the co-ordinator of the surface search and Nimrod Rescue 02 was on-Scene-Commander.

2.8.23 At 0450 Z Rescue 02 reported sighting of wreckage in position 5101 M/1245 W. Between 0505 and 0543, three USAF Chinook helicopters departed from Cork Airport to join the search. At 0556, MRCC Swansea confirmed that there were 329 people on board the aircraft (earlier reports had indicated 325 people on board).

2.8.24 A continuous search was maintained throughtout the day (24th June) but only one further body and numerous pieces of wreckage were recovered. An extensive surface search was also maintained throughout the day and instructions were passed by MRCC Shannon to Valentia Radio requestiong all shipping to recover any wreckage or bodies sighted.

2.8.25 At 0900 Z, Capt. of Department of Communications advised MRCC Shannon that Aisling was bound for Cork, ETA 1300 Z and he was assuming responsibility for collection of wreckage. MRCC were also advised by Mr. of Britoil that their two vessels 'Constine' and 'Star Orion' were enroute to Foynes having picked up quantities of wreckage.

2.8.26 At 1740 Z, SRCC Plymouth advised Shannon that the Search would terminate at 242200 Z, at 1800 Z Falmouth MRCC advised MRCC Shannon to direct the Portisheal and Valentia Radios to cancel

Urgency Broadcast from 242000 and to release HMS Challenger and Le Aisling from the search at 242000 hours. All the aircraft were released at 24000. It was also decided that Le Emer would remain at the area. At 242003 Z, a message was transmitted to all stations on R/T and W/T that air and sea search was being terminated at 242000 Z and all the participants were thanked for their assistance.

INJURIES TO PERSONS

3.1.1 Post mortem examination was carried out by Irish Authorities at Cork. At that time Wing Commander Dr. was also present. Subsequently Air Vice Marshall also reached Cork. Both of them were members of the Medical Group which had been constituted by Mr. .

3.1.2 By then 131 bodies had been recovered. None of the bodies of the flying crew were recovered. The bodies which were recovered represented 39.8 per cent of the victims. The exact seating position of passengers is not certain, because it is not known if the passengers had changed their seats after the take off of the aircraft from Montreal. On the information which is available, the passengers were supposed to have been as follows :-

Passengers :

	Seats Available	Occupied	Bodies identified
Zone A	16	1	0
Zone B	22	0	0
Upper Deck	18	7	0
Zone D	112	104 + 2	29
Zone D	86	84 + 1	38
Zone E	123	105 + 3	50
Sub-Total	377	301 +(6 infants)	117

Crew :

Flight Deck	3	3	0
Cabin	19	19	5
Total	399	329	122

3.1.3 The Post-mortem reports were examined by Wing Commander Dr. He submitted two reports being Exhibits H-1 and H-2. He was also examined in Court as Witness No. 2. Dr. who had developed a system which would indicate the severity of the accident and the injuries suffered. He used a scale from 0 to 4, with naught being no injury and 4 being a fatal lesion. Though there is some amount of subjectivity involved in the system, nevertheless categorising the injuries according to the scale does give an overall picture of what had happened to the victims. After adding up all the injury scale for a particular body, Dr. Hill in his Report Exhibit H-1 divided the injuries as under :-

		No. of victims
Mild injury (0-49) total	34.4%	45
Moderate injury (50-99)	38.9%	51
Severe Injury (100-149)	25.2%	33
Catastrophic Injury (150 +)	1.5%	2
Total	100.1%	131

3.1.4 A further break up showing the overall injury score of the recovered victims is as follows:

	Minor			Moderate			Severe			
Zone	No.	%	%	No.	%	%	No.	%	%	Total
C	8	6.1	17.8	9	6.9	17.7	4	3.1	11.4	21
D	9	6.9	20	15	11.5	29.4	9	6.9	25.7	33
E	15	11.5	33.3	15	11.5	29.4	14	10.7	40	44
Unknown	13	9.9	28.9	12	9.2	23.5	8	6.1	22.9	33
Total	45	34.4	100	51	39.1	100%	35	26.8	100%	131

3.1.5 The reports submitted by Dr. further indicted as follows

(a) There were 30 children recovered and they showed less overall injury. The average severity of injury increases from zone C to E and is significantly less in C than in Zones D and E.

(b) Flail pattern injuries were exhibited by eight bodies, five of these were in Zones E, one in Zone D, two in Zone C and one crew member. The significance of flail injuries is that it indicates that the victims came out of the aircraft at altitude before it hit the water.

(c) There were 26 bodies that showed signs of hypoxia (lack of oxygen), including 12 children, 9 in Zones C, 6 in Zone D and 11 in Zone E. There were 25 bodies showing signs of decompression, including 7 children. They were evenly distributed throughout the zones, but with a tendency to be seated at the sides, particularly the right side (12 bodies).

(d) Twenty-three bodies showed evidence of receiving injuries from a vertical force. They tended to be older, seated to the rear of the aircraft (4 in Zone C, 5 Zone D, 11 in Zone E, 2 crew and 1 unknown), and 16 had little or no clothing.

(e) Twenty-one bodies were found with no clothing, including three children. They tended to be seated to the rear and to the right (3 in Zone C, 5 in Zone D, 11 in Zone E and 2 unknown).

(f) There were 49 cases showing signs of impact-type injuries, including 19 children (15 in Zone C, 15 in Zone D, 15 in Zone E, 1 crew member and 3 unknown).

(g) There is a general absence of signs indicating the wearing of lap belts.

(h) Pathological examination failed to reveal any injuries indicative of a fire or explosion.

3.1.6 In his testimony in Court, Wing Commander Dr. further stated that the significance of flail injuries being suffered by some of the passengers was that it indicated that the aircraft had broken in mid-air at an altitude and that the victims had come out of the aeroplane at an altitude. He further explained that if an explosion had occurred in the cargo hold, it was possible that the bodies may not show any sign of explosion. It may here be mentioned that the forensic examination of the bodies do not disclose any evidence of an explosion. Furthermore, the seating pattern also shows that none of the bodies from Zone A or B was recovered, in fact as per the seating plan Zone B was supposed to have been unoccupied. This Zone is directly above the forward cargo compartment.

3.1.7 Dr. further stated that the pattern of the accident as suggested by the injuries indicated that it was a complex affair and there were at least two phases of injuries, one in the air and the other at water impact. In answer to a specific question that if there was an explosive device in the cargo hold then could the passengers who were seated have suffered such injuries, the answer of Dr. was that "it is possible". According to him, the pattern of injuries indicated that if there was an explosion in the aircraft it was more likely that the explosion had occurred in the rear cargo compartment than in the front cargo compartment. This conclusion was apparently based on the fact that, according to him,in zone E of the aircraft there were larger vertical load type injuries. Dr. was also asked if he had to make any suggestions which would minimize injuries to passengers in the event of an accident. In answer, the witness made his suggestion in the following words

> "There are very complicated things one would have to do such as rearward facing seats; having safety belts which incorporated restraint for the upper part of the body; increasing the space between aircraft seats; incorporating shocks absorbing system within the seat and using materials which do not break easily like plastic. We would also need fuel systems which would not immediately set on fire and furnishing which would be resistant to burning, and also passengers should not carry into the aeroplanes large amount of hand bags which only get in way in the event of evacuation, and I personally feel that the carriage of large amount of alchohol both in the passengers and in the aeroplane is a hazard to flight and safety. Finally the passengers

should take heed of the flight safety instructions given to them by the crew of the aeroplane".

3.1.8 Air Vice Marshal witness No. 10 in his report dated 14th November, 1985, Ex.A-48, gave his comments not only on the post-mortem reports but also on the statement of Wing Commander Dr. With regard to the post-mortem examination, the comment of AVM was as follows:

> "All victims have been stated in the PM reports to have died of multiple injuries. However two of the dead, one infant and one child, are reported to have died of asphyxia. There is no doubt about the asphyxial death of the infant. In the case of the other child (Body No. 93) there could be doubt because the findings could also be caused due to the child undergoing tumbling or spinning with the anchor point at the ankles. Three other victims undoubtedly died of drowning. There was no evidence of significant lap-belt injuries.
>
> Considering rupture of the ear-drum, without injury to skull, as a criterion to indicate rapid decompression, two cases may be considered to fall in this category.
>
> Histological examination has been carried out only in 57 bodies out of 131. Lung examination on almost all of them showed decelerative changes. Six bodies (Nos. 6,22,70,103,121 and 131) showed presence of Bone Marrow Embolism in lung sections. Though not of much significance in this accident, this finding does indicate survival after a bony injury for an undefined period of time No evidence of fire burns or explosive material, other than kerosene burns on some bodies, which I had myself seen at Cork, could be found. Kerosene burns in such acidents is a fairly common findings and is of no significance".

AVM generally agreed with the crash injury analysis on the victims which had been furnished by Wing Commander Dr. He, however, gave the following comments with regard to hypoxia, decompression and decelerative changes :

"Hypoxia : The main Post Mortem findings in hypoxia is generalised congestion if the hypoxia is of the type described as "hypoxic hypoxia". In other causes of hypoxia of more severe degree such as "histotoxic hypoxia", "asphyxia" or "drowning" additional histological findings such as petechial haemorrhages and generalised congestion, and lung findings such as haemorrhage and extrusion of alvoolar phagocytos are seen.

Decompression : The term used by Dr. is "Decompression". It is presumed that he means "Rapid/Explosive Decompression" which occurs within one Sec. and not "decompression sickness" which takes a minimum of 5 to 7 min. to occur even at 31,000 ft. altitude and which in this case can positively be ruled out.

The Post-Mortem and histological signs of rapid Decompressions are :-

(a) Possibility of rupture of ear drums without any injury to the skull.

*(b) Patchy lung haemorrhages

*(c) Emphysomatus changes

*(These occur more commonly in those cases where the individual was in the phase of breathing-in at the time of decompression.

3.1.9 If it is assumed that the aircraft suddenly broke up in mid-air at an altitude of 31,000 ft. the bodies will be at once exposed to hypoxia and rapid decompression and as a consequence will suffer body changes as mentioned above. As the aircraft/occupants start descending, they will be exposed to increasing amounts of oxygen and as soon as ;they come down below 15,000 ft. and then below 10,000 ft. the effect of hypoxia rapidly diminishes. Finally, the aircraft/individuals come down and hit the ground/water with a very heavy impact, thus submitting the individuals to extremely severe G-loads of decelerative type.

Decelerative Changes : Decelerative impact brings about well established changes in the lungs besides many other associated injuries. It is relevant to note the decelerative lung changes which are :-

(a) Patchy haemorrhages in lung.

(b) Marked emphysomatus changes.

(c) Extrusion of alvoolar phagocytes

(d) Desqummation of bronchcolar epitherium.

"Comparative study of the PM/histological findings of hypoxia, decompression and decelarative lung injuries reveal that they are more or less similar. Decelerative injury being the most severe of the three and last to occur tends to so modify the Post-Mortem and histological findings that it becomes extremely difficult and some times impossible to isolate one from the other."

3.1.10 AVM was, therefore, of the opinion that in this accident evidence of hypoxia/decompression (except in 2 cases) had not been confirmed or established.

3.1.11 The difference of opinion between Wing Commander Dr. and AVM with regard to evidence of hypoxia and decompression, is of no significance in the present case. What is important to note, however, is that they have agreed that the injury pattern does indicate break up of the aircraft in mid-air and that the occupants of Zone E had suffered the greatest amount of injuries as compared to the occupants of the other zones.

MAPPING, WRECKAGE DISTRIBUTION AND SALVAGE

3.2.1 Introduction

3.2.1.1 Oceanographic charts indicated that the depth of sea in the crash area was about 6700 feet and the site appeared to be a flat sea bed, without any valleys or hills. The immediate necessity after rescuing/searching crash victims, was to locate and recover the digital flight data recorder (DFDR) and the cockpit voice recorder (CVR). The operation was unique of its kind and had never been undertaken earlier in the world at this depth of the sea. It required an equipment which could home on the transmitted signals from the underwater locater acoustic beacons fitted on DFDR/ CVR, identify the units, clear them from attachments/wreckages, grab them and bring them to the surface.

3.2.1.2 The pressure exerted by the water at 6700 feet below mean sea level is extremely high and the temperature is very low. No light penetrates to that depth and it is pitch dark. Scarab I fitted on French Ship "Leon Thevenin" which had undertaken the challenging job of locating DFDR and CVR, and recovering the same, was not designed to operate at 6700 feet depth. Its maximum design operating depth was only 6000 feet. However, it was decided to exceed the design operating depth for this emergency operation.

3.2.1.3 By using the preliminary information of probable area of location OF CVR and DFDR as indicated by ship 'Gardline Locator', the Scarab I was lowered in the sea to locate and recover these units which it accomplished on 10.7.85 and 11.7.85 respectively.

3.2.1.4 Prior to recovery of DFDR/CVR by the ship 'Leon Thevenin', sufficient spade work was done by the ship 'Gardline Locator' (A ship provided by Accident Investigation Branch, U.K.) and 'Le Aoife' (an Irish Naval Ship). The survey of the crash area, carried out with the help of side-scan sonars fitted on these ships, had indicated a general distribution of the wreckage and a rough idea about the sizes of the parts. Each part of the wreckage was called a target. The method used for survey was triangulation with multiple passes through the crash site.

3.2.1.5 Next phase was the task of :

(a) Locating hundreds of pieces of wreckage by the combined use of sonar and video monitors.

(b) Video and still photography of the pieces of wreckage.

(c) Plotting the distribution of the wreckage.

All this was to be carried out under the directions of the Court.

3.2.2 Scarab

3.2.2.1 The means (vehicles/equipment) proposed to be used in the locating, mapping and video photography of the wreckage were the CCGS John Cabot and SCARAB II.

3.2.2.2 The John Cabot is an ice breaker of the Canadian Coast Guard. Since utilisation as an ice breaker is seasonal, the John Cabot is also equipped for submarine cable laying. In order to enlarge its capabilities in this regard, the John Cabot is equipped to have on its deck the Scarab and to operate it. Thus the John Cabot can be used for repair of submarine cables. The John Cabot has complete facilities for operation, maintenance and repair of the Scarab. This includes a Control Hut, a Test Room, Workshop, Stores etc. The John Cabot has considerable experience in work on deep sea bed.

3.2.2.3 The SCARAB II is a submersible craft assisting repair and burial of cables. As will be clear from the following details, the Scarab is not ipso facto a submarine. It is a total system for carrying out its complex functions.

3.2.2.4 The SCARAB II is a state-of-the-art system designed and built for tethered unmanned work at ocean depths of up to 6000 feet. Scarab's standard equipment are :

Two rugged manipulators.
A complete optical suite.
Six thrusters of 5 hp each.
CTEM Sonar.
Navigation System.

3.2.2.5 The manipulators have a choice of grippers/claws/cutters etc. of any required description and size. The Scarab has three TV cameras mounted on separate pan/tilt mechanism to allow real time observation and video tape documentation. A 35 mm still camera was also installed and used in the present work. There was a choice of quartz-iodide flood lights to provide illumination.

3.2.2.6 The location and control of the Scarab is accomplished through a phased array navigation system.

3.2.2.7 The Scarab was equipped with a 360° high resolution Sonar with a range of 1000 meters. The Sonar was also capable of interrogating and detecting 37 KHz and 27 KHz pingers. It can function independently of the ship's facilities and is equipped with power generators and semi-automatic handling equipment.

3.2.2.8 The John Cabot can salvage items, but it is not a salvage ship as it does not have the specialised high capacity cranes, derricks etc. required for salvage of large objects. Further, it does not have deck space for keeping large salvaged items like the wings, fuselage or tail surfaces of an aircraft as large as a 747. The John Cabot was, therefore, adequate and fully satisfactory for the work envisaged in this phase of the programme, as salvage of large items was not planned in this phase. The task was, as mentioned earlier, - locating, mapping and photography of the hundreds of pieces of wreckage. (The salvage work was part of the next phase of the programme).

*3.2.3 <u>Control and Monitoring of Operations</u>

*3.2.4 <u>Daily Monitoring of Progress</u>

3.2.5 <u>Monitoring at Cork</u>

3.2.5.1 The Scarab provided video tapes and still photographs. In the initial stages (up to 9.8.1985) the John Cabot was operating in peripheral areas and therefore few targets were found. Hence the output of videotapes was small. In fact up to 9.8.85, only about 10 targets were found and only 3 video tapes were used up. But later, when John Cabot came close to and into the crucial areas, video tapes were recorded at a fast rate. Further, still photography facility on the Scrab was activated at about this time. Therefore, arrangements were made periodically to obtain the video tapes and films from John Cabot. Video tapes and still photographs (these required to be processed) were transported from John Cabot to Cork Control Centre.

3.2.5.2 About 50 video tapes and nearly 3000 still photographs (positives and transparencies) provided the visual information on the targets.

**ICAO Note.*— Sections 3.2.3 and 3.2.4 were not reproduced.

Arrangements had to be made at Cork for such viewing and study of the video tapes and still photographs. Video equipment (TV monitor plus VCR) suitable for viewing the video tapes had to be arranged.

3.2.5.3 The still photography used special professional quality colour film (35 mm), each roll having 800 frames. The film was diapositive. These had to be developed and transparencies obtained from them. Thereafter negatives and prints had to be made. Special equipment for viewing the transparencies had to be provided for continuous work. The video tapes, transparencies and prints provided the principal means of monitoring of the results of the operation.

3.2.6 Operations

3.2.6.1 The charts prepared by 'Gardline Locator' were on a different type of grid system, and had to be translated into LAT-LONG system, for use by John Cabot. For the convenience of search/mapping operation the search area was divided into 4 blocks viz. Block 1, Block 2, Block 3 and Block 4.

3.2.6.2 The navigation system used by John Cabot is PULSE-8 system. This system needs the transponders to be placed on the sea bed. These transponders help in getting the correct fix of a target and in obtaining relative positions of the targets on the sea bed which is highly useful for revisit for the purpose of rephotography or recovery. Initially 4 transponders were placed, and subsequently the number was increased as the search operation was continued. The strategic locations for placing the transponders was decided by considering :

(a) frequencies of relative transponders,

(b) distances required between relative transponders,

(c) wreckage distribution suggested by side scan sonar plots of Eithena and Garline Locator, and

(d) size of search area.

These transponders were calibrated to match the navigation system of the ship.

3.2.6.3 In order to obtain the maximum information from search, it was decided that the Scarab search paths should be as follows :

(a) Normally the search paths should be east to west, or west to east within the individual blocks.

(b) The pattern of search should be a parallel search method.

(c) Distances between the parallel paths to be 1,200 feet (i.e. 2 cable widths), for effective use of sonar fitted on the Scarab.

(d) If Scarab deviates from its planned path for photography or recovery, it should return to its planned path for further search.

(e) In each block, the search was to be made, at least 1/2 mile (North or South) beyond the last target sighted, so as to ensure no target is missed out from the given block.

3.2.6.4 However, when there was a need to modify the search pattern, due to wreckage distribution in particular areas, the following changes were made:

(a) Expanding box type search pattern was used in Block 1.

(b) Some North to South and South to North passes were made in Block 3.

(c) In Block 3 northern end, the distances between the search passes was reduced to 600 feet i.e. 1 cable width.

However, these deviations were made basically to improve the reliability of search in specific areas, as demanded by peculiar distribution of aircraft wreckage.

3.2.6.5 To facilitate identification of the wreckage located by Scarab it was necessary to position aircraft maintenance personnel on board the ship. As the aircraft structure was badly torn, mutilated and distorted, serious difficulty was anticipated in identification of small pieces of structure. It was therefore essential that these maintenance personnel were provided with aircraft photographs, manufacturing drawings, parts catalogue, wiring diagram manuals and maintenance manuals. Since carriage of such voluminous literature was not praticable, 3M micro film reader printer machines with micro film cassettes of the above literature were produced and installed on the ship. In case of difficulty of locating any particular information, the engineers were advised to contact Cork Search Centre by telex or telephone who, in turn, could seek the desired information from the manufacturers.

3.2.7 Wreckage Distribution

3.2.7.1 The wreckage distribution as determined by the mapping of the sea bed provided some distinct distribution patterns. The depth of the wreckage varies between about 6000 and 7000 feet, and the effect of the ocean current, tides and the way objects may have descended to the sea bed was not determined, thus some distortion of an object's relationship from time of water entry to its location on the bottom cannot be discounted. In general, the items found east of long 12°43.00'W are small, lightweight and often made of a structure which traps air. These items may have taken considerable time to sink and may have moved horizontally in sea currents before settling at the bottom. Marks left on the sea bed beside some wreckage does indicate horizontal movement of the wreckage as it settled. Although badly damaged, sections 41, 42 and 44, and the wing structure were located in a relatively localized area centred about lat 51°03.30'N and long 12°47.80'W, and the wreckage scatter was oriented north/south. The wreckage scatter in this area was so dense that it is probable that some of the wreckage may not have been mapped or photographed. Section 46 and 48, including the vertical fin and horizontal stabilizer, extended in a west to east pattern with the westernmost identified aircraft component located at lat 51°02.90'N and long 12°50.1'N. The wreckage extended in a line about 110 degrees to an eastern position of lat 51°02.04'N and long 12°41.26'W, a distance of approximately 6.5 nautical miles. The aircraft structure had a random scatter pattern. That is, items such as the aft pressure bulkhead were broken into several pieces, and these pieces were located throughout the pattern. A third area which had some distinctive pattern was that of the engines, engine struts and components and was localized about lat 51°03.25'N and long 12°47.4'W in a northwest/southwest orientation. One of the operating engines was displaced 0.5 nautical mile to the north of this area, and it was also geographically separated from the wing structure. The number 3 engine nacelle strut was also separated from the rest of the engine components and was located about one nautical mile to the west-southwest at lat 51°02.87'N, long 12°48.05'W. The reasons for the displacement of the number 3 engine nacelle strut and one of the operating engines from the other engines are not known.

3.2.7.2 Details of the various targets which were identified by the Structures Group is contained in Appendix 1 of this Report.

*3.2.8 The Break up Pattern

3.2.9 Extent of Damage
Photographic and Video Interpretation of Wreckage
Photographic Interpretation

3.2.9.1 All wreckage sighted was recorded on video tapes and all major items were recorded on 35 mm positive film. During the course of the investigation, several members of the investigation team had the opportunity to view the tapes and photographs. Subsequently, when some items were recovered, it became apparent that the optical image presented on video and still film had some limitation with respect to identification of damage or damage pattern. For example, the sine wave bending of target 7 appeared in the video and photographs as a sine wave fracture, and some of the buckling on target 35 was not evident in either the video or photographs. The interpretation of damage through photographic/video evidence without the physical evidence might be misleading, and any interpretation should take this into acount.

3.2.9.2 Engines

The four operating engines were all extensively damaged. A view of the fan blades did not show signs of any rotational damage, and it could not be determined whether any pre-impact failures had occurred. The external damage to the engines varied, and at least one engine appeared to be attached to part of the nacelle strut. Except for the non-operational fifth engine, the engines could not be matched with their original positions on the aircraft.

**ICAO Note.*— Section 3.2.8 was not reproduced.

3.2.9.3 Landing Gear

The nose, wing, and body landing gear were all located. Photographic examination indicated that all the gears were in the 'up' position at the time of impact.

3.2.9.4 Flaps and Spoilers

Positive identification of all the flap and spoiler surfaces was not made. All the flap jackscrews indicated that the flaps were retracted at impact. Of the spoilers identified, six had actuators attached. The actuators were in the fully retracted position.

3.2.9.5 Section 41

Section 41, consisting of the cockpit, first-class section, and electronics bay and identified as target 192, was found in a near-inverted attitude. This section was severely damaged. The electronics bay and cockpit areas could not be located within the wreckage. The first officer's seat was found on the sea bed near section 41 wreckage.

3.2.9.6 Section 42

Portions of Section 42, consisting of the forward cargo hold, main deck passenger area, and the upper deck passenger area, were located near section 41. This area was severely damaged and some of section 42 was attached to section 44. Some of the structure identified from section 42 was the crown skin, the upper passenger compartment deck, the belly skin, and some of the cargo floor including roller tracks. The right-hand, number two passenger door including some of the upper and aft frame and outer skin was located beside section 44. Scattered on the sea bed near this area were a large number of suitcases and baggage as well as several badly damaged containers. All cargo doors were found intact and attached to the fuselage structure, except for the forward cargo door which had some fuselage and cargo floor attached. This door, located on the forward right side of the aircraft, was broken horizontally about one-quarter of the distance above the lower frame. The damage to the door and the fuselage skin near the door appeared to have been caused by an outward force. The fractured surface of the cargo door appeared to have been badly frayed. Because the damage appeared to be different from that seen on other wreckage pieces, an attempt to recover the door was made by CCGS John Cabot. Shortly after the wreckage broke clear of the water, the area of the door to which the lift cable was attached broke free from the cargo door, and the wreckage settled back on to the sea bed. An attempt to relocate the door was unsuccessful.

3.2.9.7 Section 44

Section 44 containing the aircraft structure between B S 1000 and B S 1480 including that area where the fuselage and wings were mated was located and identified. This section was severely damaged but maintained its overall shape and was lying on its right side. Part of the left wing upper skin was attached to the fuselage and a large portion, about one third of the upper wing skin, separated and was lying against the fuselage crown skin. Some of the body and wing landing gears were found beside this section of the aircraft. The gear was detached from the main structure. The interior of the fuselage was extensively damaged.

3.2.9.8 Wing Structure

The wing structure was located near the forward area of the aircraft structure and towards the northernmost area of the wreckage pattern. The wings showed extreme damage patterns with the top and bottom surfaces separated and the wing surfaces broken into segments.

3.2.9.9 Sections 46 and 48

Sections 46 and 48 contain that part of the aircraft structure aft of B S 1480 and, for purposes of this report, will include the horizontal stabilizer and vertical fin. This section of the aircraft was scattered in a west to east pattern about 6.5 nautical miles in length and exhibited severe break-up characteristics.

3.2.9.10 The aft cargo and bulk cargo doors were found in place and intact, and 5L, 5R and 4R entry doors were identified. Four segments of the aft pressure bulkhead were positively identified (targets 35, 37, 73 and 296). Much of the fuselage which was forward of the number five door and above the passenger floor area was not located, or if located was not recognisable as having come from a specific area of the aircraft.

3.2.9.11 Sections of the outer skin below the cargo area were located as was some of the cargo floor structure. Generally, the stringers and stiffeners are attached to the skin; however, the lower frames, which provided the cargo floor support, were detached from the skin. The rear cargo floor from B S 1600 to B S 1760 was located and was found to have little or no distortion; however, the lower skin and stringers were missing. A second portion of the aft cargo compartment floor containing cargo drive wheels and cargo roller trays was located. This structure was severely damaged and mangled.

3.2.9.12 The tail cone and the auxillary power unit (APU) housing were located and had received relatively minor damage; however, the APU had broken free and was never located.

3.2.9.13 A large portion of the outer skin panels showed signs of a force being applied from the inside out. On several pieces of wreckage, the skin was curled outwards away from the stringers and formers. This could have been the result of an overpressure.

3.2.9.14 The vertical tail was found in good condition, in a single piece with both rudders attached. The top cap was partially separated and a small dent was noticed in the middle of the leading edge at the bottom. A curved broken portion of fuselage was observed with a portion of the "Y" ring and pressure bulkhead attached. Another small segment of the pressure bulkhead was leaning on the lower section of the tail.

3.2.9.15 The horizontal stabilizer tail section was located and was one unit with the elevators attached. The actuator jackscrew was attached to the assembly. The stabilizer jackscrew ballnut was observed to be located at the upper jackscrew stop. This equates to a full deflection of elevator trim. Since there is nothing on the DFDR or CVR to indicate a malfunction of the trim, it is deduced that this was not the lead event. It is not known if the position of the ballnut resulted from a pilot trim selection, a result of the initial event or if it rotated to the observed position under the influence of gravity. Two-thirds of the leading edge of the right horizontal stabilizer was missing and the auxilliary spar was exposed. There was localized damage to the right-hand root of the loading edge through about a span of five ribs. The leading edge skin and part of the leading edge ribs were torn downwards. Some localized damage to the root of the left leading edge was visible with the remainder of the leading edge undamaged. There was minor damage to the trailing edge of the outboard left elevator, and a major portion of the inboard left elevator was missing.

3.2.9.16 Passenger Seats

Many of the passenger seats located among the wreckage pattern and identified as having come from section 46 and 48 appeared to have the aft support legs buckled with little or no damage to the forward support legs. Seats located in the wreckage containing sections 41, 42 and 44 appeared to have varying types of damage, that is, aft support legs only buckled, and all legs buckled. One consistent feature noted was that in the majority of seats located it was possible to ascertain that the seat belts were not fastened.

3.2.10 Salvage Operations

3.2.10.1 During recovery operation the video tapes as well as photographs of the wreckage to be recovered, were supplied to the personnel on board the ship for facilitating identification and recovery of correct targets.

3.2.10.2 Whenever any component/part of the aircraft wreckage was salvaged it was essential to immediately subject the same to inspection and to identify the damage sustained during recovery operation. In order to oversee this critical operation, the Court deputed one of its Assessors, Dr. , to be on board the ships. Under his supervision, the components/parts were thoroughly washed with fresh water, dried and treated with corrosion inhibiting compounds. A detailed inspection was thereafter carried out, observations recorded and the targets were appropriately labelled and their numbers were painted thereon. A laboratory microscope was taken on board by Dr With that, fragments of significance were segregated for further investigation. Indeed some of these fragments did give important clues.

3.2.10.3 All the investigating personnel on board the ship were provided with leather gloves, fisherman's shoes, raincoat, life floating suits, writing and labelling material, camera with coloured films, etc. Sufficient number of "body bags" were positioned on each ship to cater for the eventuality of recovery of bodies with the wreckage. This precaution helped when a body did come along with wreckage on 25.10.1985.

* 3.2.10.4

3.2.10.5 Subsequent to the accident to Japan Airlines Boeing 747 aircraft, suspected to have been caused by failure of the repair to the rear pressure bulkhead, NTSB and FAA decided to fund the U.S. Navy for a two week operation over the seas for recovery of significant pieces of wreckage. For this purpose, U.S. Navy appointed Commander a deep sea salvage expert, to head the recovery operation. An offshore supply vessel M.V. Kreuzturm, of Canada was hired by U.S. Navy to recover the wreckage with the help of Scarab on John Cabot. One nylon lift line together with winch and ram were installed on the ship prior to its sailing to Cork where it arrived on 4th October, 1985. One crane was installed on the ship Kreuzturm in Cork.

* 3.2.10.6

3.2.10.7 The structure group after studying the photographic data, had formulated a list of 32 targets for recovery on 3.10.85. A systemwise priority list proposed by the Court of Inquiry was received through Dr on 4.10.85. Using these two lists, and taking into account the operating restrictions imposed by two ship operation, a final list of targets was prepared for recovery by the ships, assigning a priority number to each target. However, as the recovery operation progressed, changes in priority list were made to achieve optimum utilisation of the ships.

*3.2.10.8

**ICAO Note.*— Paragraphs 3.2.10.4, 3.2.10.6 and 3.2.10.8 were not reproduced.

3.2.10.9 A detail log of the activities of the ships John Cabot and Kreuzturm which started the recovery operation of 10.10.85, reveals the following :

(a) The Scarab working independently recovered the following

(1) Basket at target 192 containing copilot's chair, 2 suitcases and radar antenna (12.10.85)

(2) Target 8 - Lower fuselage skin of aft cargo compartment. (11.10.85).

(3) Target 245 - Forward belly skin just aft of radome (16.10.85).

(4) Target 350 - Economy class seats and carpet (23.10.85).

(5) Target 296 - Piece of aft pressure bulkhead.

(b) The Scarab after attaching the grippers, bridal cable and lift line to the targets buoyed off the same to Kreuzturm which recovered the following targets :

(1) Target 362/396 - Forward cargo fuselage skin from station 700 to 840 and STR 41L to 43R. (16.10.85).

(2) Target 193 - Fueselage skin from station 720 to 860 and passenger door 2L (17.10.85)

(3) Target 223 - Nose landing gear pressure deck web and stiffeners, container pieces (station 260-340)(19.10.85).

(4) Target 181 - Wing skin with forward cargo compartment SLIPPED OFF WITH GRIPPERS (21.10.85) AND WAS LOST.

(5) Target 399/358 - Fuselage skin from station 780 to 940 and STR 7R to 35R with 2R door (25.10.85). A body entrapped in target 399/358 was recovered. Another body which came up to surface with the wreckage fell off into sea and was lost while hauling the wreckage on board. The recovered body was identified as of a passenger and was brought to Cork by Fisherman's vessel "Orion" at 0130 hrs. on 28.10.85 and was sent for Post Mortem etc.

(6) Target 7 - Aft cargo compartment fuselage skin from station 1480 to 1860 (26.10.85).

(7) Target 47/50 - Aft cargo floor structure with roller - tracks, frames, latch etc. from station 1600 to 1760 (27.10.85).

(8) Target 117 - Three rows of coach class seats with passenger cabin floor boards, broken floor beam (28.10.85).

(9) Target 35 - Aft Pressure Bulkhead piece (30.10.85).

* 3.2.10.10

* 3.2.10.11

3.2.10.12 After detailed macro photography of the recovered wreckage, the experts group mentioned in section 1.5.16 prepared a detailed factual report after carefully inspecting each of the targets reovered. It was decided to send the wreckage to Bombay for which necessary crates were then prepared and the large pieces of wreckage were cut along the lines indicated by the experts group to facilitate their packing.

3.2.10.13 RCMP investigators carried out a close visual and microscopic examination of the fragments recovered with the wreckage, suitcases, seats and cushions, etc. For further laboratory analysis. Dr A.D. Beveridge collected a few samples.

* 3.2.10.14

* 3.2.10.15

* 3.2.10.16

**ICAO Note.*— Paragraphs 3.2.10.10, 3.2.10.11, 3.2.10.14, 3.2.10.15 and 3.2.10.16 were not reproduced.

3.2.11 Examination of Wreckage

3.2.11.1 Floating Wreckage

Soon after the accident, a number of light weight parts of the aircraft were found floating over a wide area at the crash site. These were picked up by the ships engaged in rescue operations and were brought to Cork where they were kept in the boat yard. The floating wreckage recovery continued for four days i.e. upto 26th June.

3.2.11.2 Some of the wreckage items were subsequently washed to the west coast of Ireland. These were picked up by the Irish Police and were brought to Cork. Some wreckage items were taken by a ship to Halifax, Canada. These were flown to Cork by the Canadian Aviation Safety Board. With the assistance of Air India engineers, the wreckage items were identified, labelled, photographed and laid out in the boat yard hangar for examination.

3.2.11.3 The wreckage was initially examined at Cork by the Structures, Power Plant and Systems Group. It was subsequently transported to Bombay for further examination. A few wreckage items which were taken by the Spanish trawlers to Madrid were also transported to Bombay. Some wreckage items had washed to the west coast of England. These were collected by the Accident Investigation Branch of UK and were transported to Cork and then to Bombay.

3.2.11.4 The floating wreckage recovered constituted approximately 3 to 5 per cent of the aircraft structure. The major items of the wreckage recovered were :

Various leading edge skin panels of LH nd RH wing, LH wing tip, spoilers, leading edge and trailing edge flaps, engine cowlings, flap track canon fairings aft end pieces, landing gear wheel wall doors, pieces of elevator and aileron, toilet doors, cabin floor panels, cabin overhead and upper deck bins, passenger seats, life vests, slide rafts, hand baggages, suitcases etc. and three empty oxygen bottles.

* 3.2.11.5

3.2.11.6 Wreckage Salvaged from Sea

The wreckage salvaged from the sea was visually examined at Cork by the Committee of Experts as mentioned in section 1.5.16 and the observations thereon recorded. Subsequently detailed metallurgical examination was carried out at the Bhabha Atomic Research Centre, Bombay by Dr. and Dr. of B.A.R.C., Mr. and Dr. of National Aeronautical Laboratory and Mr. of the Explosives Research and Development Laboratory, under the guidance of Dr. . During this examination, representatives of CASB, CP Air and Boeing were present in the first week. These representatives left Bombay while the metallurgical examination was being carried out. The metallurgical examination was continued and the aforesaid group submitted the metallurgical report to the Court in December, 1985.

3.2.11.7 Although all the recovered wreckage was examined, only those items exhibiting characteristics which provide some evidence as to what may have happened to the aircraft during its final moments of flight are discussed herein below :

3.2.11.8 Target 7 - Lower Fuselage Skin Panel

This skin panel was located below the aft cargo area and contained the keel beam. Target 7 extended from B S 1480 to 1850 and was about eight feet in width and 32 feet in length. The left edge had a full length rivet line tear and the torn edge was buckled in waves, like the trace of a sine wave. One the right side, between the one quarter and midway segment, a large flap of skin was attached. The skin was folded aft, diagonally underneath, from right to left and the paint was scoured off the leading edge. The forward break was at the joint at B S 1480. The skin tear located at about B S 1860 was irregular in nature. The forward keel joint splice plate was bent, and the keel joint bolt holes were distored and elongated.

3.2.11.9 This panel was examined by the committee of experts at BARC and according to their report the keel beam trunnion fitting beneath

*ICAO Note.— Paragraph 3.2.11.5 was not reproduced.

the outer chord of the station 1480 bulkhead had fractured at the aft set of bolt holes. The fracture surface of the right side of the trunnion fitting was clean. As per the report, it was typical of overload failure in tension. The fracture surface of the left side of the trunnion fitting was covered with corrosion products, especially, at one corner, due to sea water. After cleaning this area by the recommended techniques, scanning electron microscopy revealed morphology of overload fracture consisting of dimples. Away from this corner also the fracture was similar as being due to overload. There was no evidence of there having been any fatigue failure.

3.2.11.10 At B.A.R.C., a sample was cut from the corroded corner of the failed left side trunnion fitting and metallographic examination was carried out on the same. The said examination showed on a face perpendicular to the corroded fracture surface, pits due to corrosion by sea water. The basic microstructure was however free from intergranular cracking. It was thus concluded by the experts that the material in the region corroded by sea water had not suffered stress corrosion cracking which generally manifests as intergranular cracking.

3.2.11.11 A piece of the trunnion fitting was cut and the hardness and electrical conductivity values were measured by the said experts. As per their report, the electrical conductivity values were within the specified limits.

3.2.11.12 <u>Target 8 - Lower Fuselage Skin Panel</u>

This skin panel was located below the aft cargo area and extended from B S 1860 to 1960 and from stringer 46L to 46R. The forward end of target 8 matched with the aft end of Target 7. A region of fracture along the rivet holes near stringer 46L was marked for SEM examination. SEM examination after cleaning revealed that the fracture was characterised by dimples along its length, including areas adjacent to the edges of the rivet holes. These features are consistent with an overload mode of failure.

3.2.11.13 According to the metallurgical report, there was no evidence of fatigue failure on this target.

3.2.11.14 Target 35 - Portion of Rear Pressure Bulkhead

Looking forward from behind the aircraft, this segment of pressure bulkhead occupied the 9 to 1 O'Clock position, the piece from 12 to 1 O'Clock position had the flange from the outer ring attached. The web below the outer ring flange had areas of buckling. From the 11 to 12 O'Clock position the outer edge showed sinusoidal buckling, and the edge sector at 9 O'Clock position was partially collapsed and its edge was turned under. Samples taken for optical stereomicroscope and SEM examination revealed that the fracture characteristics were consistent with an overload mode of failure.

3.2.11.15 According to the metallurgical report, there was no evidence of fatigue or any other mode of failure.

3.2.11.16 Target 296 - Portion of Rear Pressure Bulkhead

Looking forward from the rear of the aircraft, this segment of the bulkhead occuped the 7 to 9 O'Clock position. Optical and SEM examination were undertaken on this item.

3.2.11.17 The fracture along the left-hand edge of target 296 (viewed from the rear) was examined optically prior to removing any representative samples. The fracture was at the rivet line at a skin splice, except for a length of fracture about 15 inches long near the forward end, which was through the skin away from the rivet line. Most of the rivet holes along the fracture path showed some slight elongation and skin deformation.

3.2.11.18 Representative fracture samples were cut from the left-hand side and circumferential fracture edges of the fracture surfaces. Optical and SEM examination revealed that the fracture characteristics are consistent with an overload mode of failure.

3.2.11.19 Target 47 - Aft Cargo Floor Structure

This portion of the aft cargo compartment was located between B S 1600 and B S 1760. No significant observation was noted. There was no evidence to indicate characteristics of an explosion emanating from the aft cargo compartment.

3.2.11.20 <u>Target 117 - Floor with Seats Attached</u>

These seats were right-section doubles, located between B S 1880 and 1980 and were from rows 46, 47 and 48, F and G (Zone E). The seats were displaced to the left with the rear legs buckled to the left. The front leg supports exhibited only minor damage. The middle and rear doubles had aisle-side seat arms bent to the right. There was no impact damage to the seat backs or seat pans, and all life vests except one were gone from the underseat container bags.

3.2.11.21 In the metallurgical report it is stated that on an examination of this target it was also found that on the underside of this floor near the forward end, a number of dents and impact marks were observed. This region appeared to have suffered shrapnel penetration. This area was radiographed but no metallic fragment was detected.

3.2.11.22 <u>Target 193 - Fuselage Side and 2L Entry Door</u>

The fuselage segment was located between B S 720 and 840. The door and fuselage skin were buckled outwards, approximately in line with the buckling on the fuselage and 2R entry door directly opposite.

3.2.11.23 <u>Target 399 - Fuselage around 2R Door</u>

This target is shown in Fig. 399-1. A detailed description is given below :

TARGET 399 — Fuselage Station 780 to 940 in the longitudinal direction and stringer 7R down to stringer 35R circumferentially.

This piece contained five window frames, one in the 2R passenger entry door. Three of the window frames, including the door window frame, still contained window panes. Little overall deformation was found in the stringers and skin above the door. The structure did contain a significant amount of damage and fractures in the skin and stringers beneath the window level. In the area beneath the level of the windows, the original convex outward shape of the surface had been deformed into an inward concave shape. Further inward concavity was found in the skin between many of the stringers below stringer 28R. The skin at the forward edge of the piece was folded outward and back between stringers 25R and 30R. Over most of the remaining edges of the piece a relatively small amount of overall deformation was noted in the skin adjacent to the edge separations. Twelve holes or damage areas were numbered and are further described.

No.1 : Hole, 5 inches by 9 inches with two large flaps and one smaller curl, all folded outward. Reversing slant fractures, small area missing.

No.2 : Hole, 2 inches by 3/4 inch, one flap folded outward, reversing slant fractures, one curled sliver, no missing metal.

No.3 : Triangular shaped hole about 2 inches on each side. One flap, folding inward, with one area with a serrated edge. No missing metal, extensive cracking away from corners of the hole, reversing slant fracture.

No.4 : Tear area, 8 inches overall, with deformation inward in the centre of the area. Reversing slant fracture.

No.5 : Fracture area with two legs measuring 14 inches and about 24 inches. Small triangular shaped piece missing from a position slightly above stringer 27R. Inward fold noted near the joint of the legs. An area of 45° scuff marks extend onto this fold.

No.6 : Hole about 2.5 inches by 3 inches with a flap folded outward, reversing slant fracture. Approximately half the metal from the hole is missing.

No.7 : Hole about 3 inches by 1 inch, all metal from the hole is missing. Fracture edges are deformed outward.

No.8 : Forward edge of the skin is deformed into an "S" shaped flap. Three inward curls noted on an edge.

No.9 : Inwardly deformed flap of metal between stringers 11R and 12R at a frame splice separation. No evidence of an impact on the outside surface.

No.10 : Door lower sill fractured and deformed downward at the aft edge of the door.

No.11 : Frame 860 missing above stringer 14R. Upper auxilliary frame of the door has its inner chord and web missing at station 860. A 10 inch piece of stringer 12R is missing aft of station 860.

No.12 : Attached piece of floor panel (beneath door) has one half of a seat track attached. The floor panel is perforated and the lower surface skin is torn.

3.2.11.24 Much of the damage on this target was on the skin and stringers beneath the window level, i.e., on the starboard side of the front cargo hold. The inside and outside surface of the skin in this region are shown in Fig. 399-2 and 399-3 respectively. There were 12 holes or damaged areas on the skin as described above, generally with petals bending outwards. The curl on a flap around hole no.1 shown in Fig. 399-4 has one full turn. This curl is in the outward direction. Cracks were also noticed around some of the holes. Part of the metal was missing in some of the holes. The edges of some of the petals showed reverse slant fracture. In one of the holes, spikes were noticed at the edge of a petal.

3.2.11.25 When this target was recovered from the sea, along with it came a large number, a few hundreds, of tiny fragments and medium size pieces, All of the fragments were recovered from the area below the passenger entry door 2R. One of the medium size pieces recovered with this target was a floor stantion, about 35 inches long, shown in Fig. 399-5. It is a square tube. It had the mark station 880 painted on its inner face, i.e. facing the centre line of the cargo hold. The part number printed on this station is 69B06115 12 and the assembly number is ASSY 65B06115-942 E3664 1/31/78*. It was confirmed that this stantion belongs to the starboard side of the forward cargo hold. The inner face of the stantion had a fracture with a curl at the lower end, the curl being in the outboard direction and up into the centre of the station. Fig. 399-6 is a print from the radiograph of this station. The inward curling can be seen clearly in this figure. Curling of the metal in this manner is a shock wave effect.

3.2.11.26 A piece near the fracture edge of this stantion was cut, and examined metallographically. Fig. 399-7 and 399-8 show the micro-structure of this piece. Twins are seen in the grains close to the fracture edge. The normal microstructure of the stantion material is free from twins as shown in Fig. 399-9.

3.2.11.27 Fig. 399-10 shows a collection of small fragments recovered along with target 399. There were some curved fragments with small radius of curvature (A). Reverse slant fracture (B) was noticed in some of the skin pieces. A piece 3/4" x 1/2" and 3/16" thick was found to have three blunt spikes at the edge (C). This piece was metallographicaly polished on the longitudinal edge. The microstructre of the piece is shown in Fig. 399-11. It may be seen that the grains in this fragment also contain a large number of twins.

3.2.11.28 Target 362/396 Forward Cargo Skin

This piece included the station 815 electronic access door, portions of seven longitudinal stringers to the left of bottom centre and five longitudinal stringers to the right of bottom centre. The original shape of the piece (convex in the circumferential direction) had been deformed to a concave inward overall shape. Multiple separations were found in the skin as well as in the underlying stringers. Further inward concavity was found in the skin between most of the stringers.

3.2.11.29 The two sides of this piece are shown in Fig. 362-1 and 362-2. This piece has 25 holes or damaged areas in most of which there are multiple petals curling outwards. These holes are numbered 1 to 3, 4a, 4b, 4c and 5 to 23. These are described below. Unless otherwise noted, holes did not have any material missing :

No.1 : Hole with a large flap of skin, reversing slant fracture.

No.2 : Hole with multiple curls, reverse slant fracture.

No.3 : Hole with multiple flaps and curls, reversing slant fracture, one area of spikes (ragged sawtooth)

No.4A : One large flap, reverse slant fracture, one area of spikes.

No.4B : Hole with two flaps.

No.4C : Hole with two flaps, one area of spikes

No.5 : HOle with two flaps.

No.6 : Braching tear from the left side of the piece, reversing slant fracture.

No.7 : Hole, with one flap, one curl and one area of spikes.

No.8 : Very large tear from the left side of the piece with multiple flaps and curls, reversing slant fracture and at least two areas of spikes.

No.9 : Hole with multiple flaps, one curl

No. 10 : 2.5 inch tear

No.11 : One flap

No. 12 : Grip hole, plus a curl with spikes on both sides of the curl.

No.13 : "U" shaped notch with gouge marks in the inboard/outboard direction. Three curls are nearby with one are of spikes. Gouges found on a nearby stringer and on a nearby flap.

No. 14 : Nearly circular hole, 0.3 inch to 0.4 inch in diameter. Small metal lipping on outside surface of the skin. Most of the metal from the hole is missing.

No. 15 : Hole in the skin beneath the first stringer to the left of centre bottom. Small piece missing.

No. 16 : Hole in the stringer above hole No. 15. Most of the metal from this hole is missing.

No. 17 : Hole through the second stringer to the left of centre bottom, 0.4 inch in diameter. The hole encompassed a rivet which attached the stringer to the outer skin. Small pieces of metal missing.

No. 18 : Hole at the aft end of the piece between the third and fourth stringers to the left of centre bottom. The hole consisted of a circular portion (0.4 inch diameter), plus a folded lip extending away from the hole. The metal from the circular area was missing.

No. 19 : Hole with metal folded from the outside to the inside, about 0.6 inch by 1.5 inch. Flap adjacent to the hole contained a heavy gouge mark on the outside surface of the skin.

No. 20 : Hole containing a piece of extruded angle.

No. 21 : Hole containing a piece of extruded angle.

No. 22 : Hole with one flap.

No. 23 : Hole about 0.3 inch in diameter, with tears away from the hole. Small piece missing.

3.2.11.30 Fig. 362-3 to 362-7 show a few of these holes. There were also cracks or tears around some of the holes. The curls around some of the holes had nearly one full turn. In the large tear between body stations 700 and 740 and stringers between 41L and 45L, there were many pronounced curls as shown in Fig. 362-8. On the edges of the petals around several holes, reverse slant fracture was seen at a number of places. This slant fracture is at an angle of about 45° to the skin surface, the fracture continuing in the same general direction but with the slope of the slant fracture reversing frequently.

3.2.11.31 Sharp spikes were observed at the edges of the holes or at the edges of the petals around the holes No. 3, 4A, 4C, 7, 8 (at two locations), 12, 13 and 16. Some of the spikes are shown in Fig. 362-9 to 362-12. One of the holes, No. 14, on the skin was nearly elliptical with metal completely missing, as shown in Fig. 362-13. On the inside surface of the skin, paint surrounding this hole was missing. Hole No. 16 was through the hat section stringer, as shown in Fig. 362-14. In this, most of the metal was missing. On the inside of the hat section, the fracture edge of this hole had spikes, as shown in Fig. 362-15. Hole No. 17 was through the stringer and the skin, as shown in 362-16.

3.2.11.32 Through holes No. 20 and 21, extruded angles were found stuck inside, as shown in Fig. 362-17 and 362-18 respectively. In the petal around hole No. 20, there was an impact mark by hit from the angle as seen in Fig. 362-19 photographed after removing the angle. Such a mark was not present in the petals around other holes.

3.2.11.33 On the skin adjacent to hole No. 13 gouge marks were noticed, Fig. 362-20. These marks were on the inside surface of the skin. To check whether these could be due to rubbing by the bridal cable of Scarab during the recovery operations, a sample of bridal cable was obtained from "John Cabot" and gouge marks were produced by pressing this cable against an aluminium sheet. The gouge marks thus produced, as shown in Fig. 362-21, appear to be different from those observed near hole No. 13.

3.2.11.34 A piece surrounding hole No. 14 was cut out and examined in a Jeol 840 scanning electron microscope at the Naval Chemical and Metallurgical Laboratory, Bombay. Fig. 362-22 and 362-23 are the scanning electron micrographs showing the inside surface and outside surface of the skin around this hole. Flow of metal from inside to outside can be seen from these figures. Energy dispersive x-ray analysis was carried out on the edges of this hole. Only the elements present in this alloy and sea water residue were detected.

3.2.11.35 A portion of the skin containing part of hole No. 14 was cut, polished on the thickness side of the skin and examined in a metallurgical microscope. Fig. 362-24 shows the microstructure of this region. The flow of metal along the edge of the hole can be seen from the shape of the deformed grains near the hole. This can be compared with the bulk of the grains shown in Fig. 362-25, away from the hole. In addition, in Fig. 362-24, a series of twin bands can be seen in some of the grains near the hole. Fig. 362-26 shows these bands at a higher magnification. Normal deformation rates at various temperatures do not produce such twinning in aluminium or its alloys. It may be noted that this microstructural feature is absent in the microstructure of the skin, away from hole No. 14, Fig. 362-25.

3.2.11.36 Metallography was also carried out on a petal around hole No.7 and on a curl with spikes around hole No. 12. The microstructures indicate twins, however they could not be recorded due to their poor contrast.

3.2.11.37 Small pieces containing the spikes around holes No. 12 and 16 were cut and energy dispersive x-ray chemical analysis on the region of spikes in both was carried out in the Jeol 840 SEM. Only elements present in the alloys and sea water residue were detected.

3.2.11.38 A number of small fragments were found along with the forward cargo skin in target 362. Amongst them was a piece from the web of a roller tray. This has pronounced curling of the edges towards the drive wheel, Fig. 362-27.

3.2.11.39 Another small fragment was found from the above target. This piece, identified as specimen No. 12 in box No. 1, target 362, has a number of spikes along the edge. A scanning electron micrograph of the spikes is shown in Fig. 362-28. The sides of the spikes on SEM examination revealed elongated dimples as shown in Fig. 362-29, characteristic of shear mode of fracture. Metallography was carried out on the thickness side of this specimen. Fig. 362-30 and 362-31 show the microstructure near the apex of the spike and at the root of the spike respectively. Extensive twinning can be seen in these regions of the spikes.

3.2.11.40 Another fragment recovered with target 362 and identified as specimen No. 8 in box No. 1, also showed extensive twinning. The microstructure is recorded in Fig. 362-32.

3.2.11.41 Reference has also to be made to two other reports concerning wreckage.

3.2.11.42 The floating wreckage recovered was initially examined at Cork. On 25th June, Mr. a retired investigator of AIB, UK, was requested to examine the floating wreckage recovered and other materials with specific reference to the possibility of explosive sabotage having taken place. Mr. examined the floating wreckage, passenger clothings and the other materials recovered from the crash victims The findings of Mr. on the material available at that time are summarised below :

a. Taking the scatter of the wreckage and bodies into consideration and the condition of the limited wreckage recovered indicates that the aircraft had broken up in flight before impact with the sea.

b. Detailed examination of the structural wreckage recovered did not reveal any evidence of collision with another aircraft. Nothing was found suggestive of an external missile attack.

c. There was no evidence of fire internal or external.

d. There was no evidence of lightning strike.

e. Examination of all available structural parts recovered, did not reveal any evidence of significant corrosion, metal fatigue or other material defects. All fractures and failures were consistent with overstressing material and crash impact forces.

f. Examination of clothing from the bodies did not show any explosive fractures or any signs of burning. The seat cushions and head cushions also did not show any explosive characteristics.

g. The damage to the suitcases (14 large and 29 small) which were examined was due to impact crash forces. The presence of 14 large suitcases could, however, indicate that one of the baggage containers had been broken to permit these suitcases to escape.

h. A number of lavatory doors and structure also did not show any damage consistent with explosion. The flight deck door showed no explosion damage inside or outside.

i. The circumstantial evidence strongly suggests a sudden and unexpected disaster occurred in flight.

j. There was no significant fire or explosion in the flight deck, first and tourist passenger cabin including several lavatories and the rear bulk cargo hold.

3.2.11.43 The other report dated 30th November, 1985 is of Mr. Mr. had examined the wreckage and had also taken part, though only for a few days, in the metallurgical examination which was being conducted at BARC, Bombay.

3.2.11.44 Mr. examined practically all the items of wreckage which had been brought to BARC and in his report he has dealt with all of them. His report contained a description of the recovered items and also his comments thereon.

3.2.11.45 With regard to the aforesaid target 362, he observed that there were about 20 holes in it clearly resulting from penetrations from inside.

3.2.11.46 He further stated that :

"In addition to the fact that perforation was from inside there are certain features which suggest that they were made by high velocity fragments such as are produced by an explosion. These features are :

(a) Presence of toothed or spiked edges at some parts of the metal which had petalled out from the perforations.

"Tardif and Sterling (Canadian Aeronautics and Space Journal, 1969, 16, 1, 19-27) obtained spiked fractures in fragments from sheet alloy subjected closely to an explosion. They stated that they had not obtained this effect in fractures otherwise produced.

(b) Presence of marked curling, in some cases of more than 360°, of some of the petals.

Tradif and Sterling stated that such curling was a feature of explosively produced fragments.

(c) The virtual absence of scratches or score marks on the petals such as might be expected if something were slowly forced through the metal.

(d) The virtual absence of other impact marks on the inside surface such as might have been produced by a massive impact with a substantial object. This suggested that the production of at least many of the perforations were separate independent events.

(e) One perforation (identified as No. 14) resembles a "bullet hole", that is cleanly punched out - a type of hole usually associated with a high velocity missile.

"There is evidence that the forward part of this item had been folded back inwards along the line of station 760 and then bent back again along a line slightly forward of this station.

"Such folding, may be violently produced on impact with the water, could have brought broken metal of stringers or stiffeners into forceful contact with the internal surfaces producing perforations outwards. The overlap of such folding would conceivably have covered the area up to station 800 and thus included most of the perforations.

"One hole identified as No. 13, was almost certainly caused by a slipping wire rope used as a sling.

" Part of the inner surface, aft of station 780 was superficially blackened as if by soot from a fire. Swabs were taken by me of this area and are being examined by R.A.R.D.E. for evidence of fire or explosives".

3.2.11.47 There were several hundred small fragments which were recovered from the same general area as Target 362. While dealing with these Mr. observed that the production of a large number of small fragments is generally regarded as indicative of an explosion. One piece out of this was isolated, which was about one inch square of sheet alloy, and it was noted by Mr. that this piece had characteristic spikes on one edge similar to those described by Tardif and Sterling. (This piece is the same as shown in Fig. 362-28).

3.2.11.48 Mr. also examined a few suit cases which had been recovered. One particular suit case to which reference was made by him was of red plastic material with blue lining. With regard to this he stated that the damaged lining, severely tattered, resembles that of one found after an explosion in an aircraft in Angola. In that case microscopic examination showed definite evidence of damage by an explosion.

3.2.11.49 The later part of the report of Mr. contained his opinion. With regard to Target 362 his opinion was as follows :

"The features discernible to a careful close visual examination point towards the possibility of an explosion but taken alone do not justify a firm conclusion.

"Curling of petals and spiked or toothed fractures may be observed in other events than explosions despite the failure by Tardif and Sterling to obtain them in their limited number of attempts. It is probable that these features indicate a rapid rate of failure but not necessarily of a rapidity which could only be produced by an explosion.

"A more detailed study, metallurgical and fractographic, is required.

"The studies by Tardif and Sterling were done on fragments produced from aluminium alloy in contact with the explosive. Very little information is available on the behaviour of aluminium alloy some distance from the explosive and subjected to attack by secondary fragments. To determine this some trials will be necessary, to obtain reference samples for comparison.

"The single "bullet hole", No. 14, strongly supports an explosion hypothesis but, being the sole example of its kind, is not , by itself determinative.

"If the forward part of this item was forcefully and rapidly folded back to impact on the other part it might explain the other features apparent to visual examination. It would require detailed laboratory examination and tests to eliminate this possibility".

3.2.11.50 The opinion of Mr. about the small fragments was as follows :

"The production of a large number of small fragments is generally regarded as a pointer towards an explosive cause but cannot be relied upon unless it is clear that they could not have been produced by some other means. It is known that the break-up of an aircraft at high speed may produce great fragmentation.

"The single spiked fragment must be regarded as important but a single specimen is not, by itself, determinative."

3.2.11.51 It appeared to the Court that the report of Mr. required certain clarifications. It was suggested to Boeing Commercial Airplane Company by the Court that Mr. should appear as a witness. The Court received a message to the effect that Mr. felt that he could not add anything useful to his report.

3.2.11.52 A close examination of the report of Mr. shows that the opinion expressed by him in the later part of the report is at considerable variance with the observations contained in the earlier part of the report. Particularly with regard to Target 362 and the small fragments, Mr. has stated in his observations that there was strong evidence of explosion. In his opinion, however, he has stated that more detailed study is required. It is interesting to note that though Mr. has referred to the opinion of Tardif and Sterling, he has not chosen to contradict the conclusions arrived by them. Mr. has also not stated as to what could possibly have caused the special features which were noted on Target 362.

3.2.11.53 We find the metallurgical report inspires more confidence. Not only is reference and reliance made in the report to other expert opinions contained in various articles written by experts all over the world, certain explosion experiments were also carried out by the experts which led them to the same conclusion.

3.2.11.54 The particulars of the experiments so carried out and the results obtained therefrom have been stated in their report as follows :

EXPLOSION EXPERIMENTS

"To determine the damage by high velocity fragments or shock waves on a structure similar to the one in aircraft cargo hold, the following experiments were conducted on November 30 and December 1, 1985 at the Explosives Research and Development Laboratory, Pune, using plastic explosive (PEKI) and different mixtures of plastic explosive and TNT. The explosive was kept in a box made of sheet metal of 6" x 6" x 6" of 1/16" thickness. This box was kept inside another box made of sheet metal 2' x 2' x 2' of .04 or .06" thickness. The boxes were made of 2024 aluminium alloy sheets used for aircraft skin. To the inner surface of the outer box, hat section stringers similar to those used in the aircraft were riveted. The quantity of explosive used in the inner box was varied from 60 g to 100 g. The explosive was detonated with an electrical detonator. After the explosions the fragments and the panels were collected and examined.

"Experiments were also conducted to produce explosive damage on skin panels, individual hat section stringers and individual stantion tubes. In the case of stantion tubes experiments were carried out placing the explosive charge both inside and outside. The quantity of explosive used was varied from 5 g to 50 g.

"Various types of damages were recorded on all the targets. These include punched holes, petaling and curling around holes, spikes at fracture edges, curved fragments with small radius of curvature and reverse slant fracture. Fig. EXP-1 shows a collection of fragments. The features mentioned above are shown in Fig. EXP-2 to EXP-7. It may be noticed that the features produced by experimental explosion were similar to the features observed largely in target 362 of the wreckage. The small fragments had features similar to those in the fragments from targets 362 and 399.

"Metallography was carried out in (a) a specimen surrounding a punched hole in the skin (b) a specimen surrounding a hole in the stringer,

(c) a curl in the stantion and (d) spikes in a fragment. In all these cases, the grains adjacent to the area of explosive damage are having twins. Two typical microstructures are shown in Fig. EXP-8 and EXP-9. Away from these areas the microstructure is normal. Thus it is confirmed that twinning in the microstructure of these structural members is a unique feature of explosive fracture, not produced by any other means known so far."

3.2.11.55 The findings in the said metallurgical report are also strengthened by the observations of in the article "Investigating Explosive Sabotage in Aircraft" published in the International Journal of Aviation Safety, March 1985, p. 43. Mr. is an acknowledged authority in the detection of explosive sabotage in aircraft. The conclusions contained in the article are based on his review of incidents of explosion between 1946 and 1984 which were known to him. Some of the conclusions arrived at by him which were relevant in the present case are when he states "Generally speaking, the smaller the fragment, higher the velocity of the detonation. Minute fragmentation is indicative of high explosive having been used, and provides clues to the focal point or region of the explosion. The mode of break up of the aircraft itself and its sequence of failure is usually very complicated and quite without the logic dictated by normal aerodynamic overstressing".

3.2.11.56 Mr. has also observed that curling, cork-screwing, and saw tooth edges may also be indicative of an explosion though such fractures by themselves may not be conclusive evidence that an explosion was involved. Firmer evidence, according to him, was of fusing of metal, scorching, pitting and blast effect. He further states that "Perhaps the most conclusive material evidence to be found on metal specimens is cratering, very often in groups, often minute and numerous".

3.2.11.57 Mr. also refers to the positive explosive signatures which remain on a detonation in an aircraft. These positive signatures, according to him, are as follows :

"(a) The formation of distinctive surface effects such as pitting or very small craters formed in metal surfaces, caused by extremely high velocity impacts from small particles of explosive material. Such craters, when viewed under the microscope, have raised and rolled over edges and often have explosive residue in the bottom of the crater.

"(b) Small fragments of metal, some less than 1 mm in diameter, which, under the scanning electron microscope, reveal features such as rolled edges, hot gas washing (orange peel effect, surface melting and pitting and general evidence of heat; such features have been proved and observed following explosive experiments with known explosives). Supporting strong evidence would be if such fragments (normally found embedded in structures, furnishing or suitcases) were found embedded in a body where evidence of burning of tissue is present at the puncture entry and where the fragment came to rest.

"(c) As well as surface effects on metal fragments produced by explosives there are deformation mechanisms which are peculiar to high rates of strain at normal temperature. At normal rates of strain metals deform by usual mechanism associated with dislocation movement. However, because this process in an explosion is thermally activated at very high rates of strain, there is insufficient time for the normal process to occur. In some metals such as copper, iron and steel, deformation in the crystals of the metal takes place by 'twinning', that is to say by parallel lines or cracks cutting across the crystal. Such a phenomenon can occur only if the specimen has been subjected to extreme shock wave loading at velocities in the order of 8000 m/sec. Such specimens, usually distorted must be selected with care, prepared in a metallurgical laboratory, polished, mounted and microscopically examined. Where such twinning of the crystals is found it establishes (a) that the specimen was close to the seat of the explosion and (b) that a military type explosive had been used with a detonating velocity of 8000 m/sec or more. Twinning is rarely produced when shock impact loadings are below 8000 m/sec.

"The above features, singly or combined, are considered to be proof positive evidence of a detonation of a high explosive; they could not be produced in any other way."

3.2.11.58 The metallurgical report indicates that the microscopic examination (conducted by them) discloses such features being present which had been described as positive signatures of the detonation of an explosive device in an aircraft by Mr. . Furthermore, twinning effect has also been noticed at a number of places - around holes and in fragments. These have been categorised by Mr. as positive signature of an explosion.

3.2.11.59 In the primary zone of explosion, metallic structures disintegrate into numerous tiny fragments and usually these fragments contain the above mentioned distinct signatures of explosion. In the present case the explosive damage had occurred at an altitude of 31000 feet when the aircraft was flying over the ocean. The fragments that formed due to explosion must have been scattered over a wide area and it is impossible to locate and recover all of them from the ocean bed. Nevertheless, some of the fragments which were recovered along with the targets 362 and 399 do contain signatures of explosive fracture.

3.2.11.60 From the aforesaid discussion it would, therefore, be safe to conclude that the examination of targets 362 and 399 clearly reveals that there had been a detonation of an explosive device on the Kanishka aircraft and that detonation has taken place not too far away from where these targets had been located.

FIRE

3.3.1 There is no evidence that there was any fire on board the aircraft before it met with the accident.

3.3.2 Amongst the floating wreckage, however, was found, what was later on identified as, a spares equipment box belonging to this aircraft. This box was charred on one side and partially on the bottom. The depth of charring suggested that the burning time was three to four minutes. This box contained some sand and small shellfish. The flesh from the shellfish appeared to be charred, indicating that the box was subjected to fire after the occurrence.

FLIGHT RECORDERS

3.4.1 Recovery of Flight Recorders

3.4.1.1 Recovery of the flight recorders was a very difficult and challenging job. At the site of accident, depth of water is about 6700 feet. The job involved fixing the location of recorders and then retrieving them. For this purpose three ships viz. Guardline Locator (a ship provided by Accident Investigation Branch of U.K.), Le Aoife (an Irish Naval Ship) and Leon Thevenin (a French Cable laying ship, chartered by the Government of India) were utilised. Guardline Locator and Le Aoife were solely for fixing the positions of recorders and also had the capability to lift the recorders with the help of its Scarab.

3.4.1.2 Both the Cockpit Voice Recorder and the Digital Flight Data Recorder were fitted with Dukane Underwater Acoustic Beacons (Pingers) which enabled establishing the location of flight recorders under water. The beacons are designed to provide a signal at 37.5 ± 1 Khz frequency that can be heard for approximately 2 miles in any direction for 30 days after water entry. Its high strength case permits operation in water depth to 20,000 feet. Its pulse repetition rate is not less than 0.9 pulse per second.

3.4.1.3 On 4th July, 1985, Guardline Locator reported strong possibility of two separate sound sources of frequencies between 39 KHz and 42 KHz. On 5th July, Guardline Locator gave coordinates of an area, which it believed contained the pinger. Guardline Locator later reported that using a Dukane Hand Locator, it had located pinger (2) at 5102.6N, 1248.6W. Leon Thevenin then concentrated its search in this area for retrieving the recorders.

3.4.1.4 In response to a query, Messrs Dukane Corporation advised that Pinger transducer is made of ceramic and if cracked during impact, its frequency could be elevated. The pulse rate should, however, be uneffected. Keeping this in mind, the Leon Thevenin increased its Sonar Band one upper frequency limit from 40 KHz to 45 KHz.

3.4.1.5 On 9th July at about 2300 hours the Scarab of Leon Thevenin located the Cockpit Voice Recorder at 5102.67N, 1248.93W and the recorder was brought on the deck at 0747 hrs on 10th July. The CVR was kept in a drum filled with water. The Scarab was again lowered on 10th July in the same area and at about 2130 hours faint signals were picked up on Sonar. By about 2200 hours the signals became louder and the pulse rate frequency was calculated to be 72 transmissions per minute. At about 2230 hours the DFDR was also located at 5103.10N, 1249.59W and it was brought on deck at 0245 Z on 11th July.

3.4.1.6 The DFDR was also placed alongside the CVR in the drum filled with water. Leon Thevenin was then advised to return to Cork with the Flight Recorders. Leon Thevenin reached Cork on the morning of 12th July and the flight recorders were placed in two specially fabricated water tight steel containers filled with water. The recorders were then carried to Bombay on the same day by Mr. Regional Controller of Air Safety, Bombay, accompanied by Mr. of Air India for preparing read-outs and transcript of the recorders. Necessary precautions were taken to ensure that the data recorded was not affected during transportation to Bombay.

*3.4.1.7

3.4.2 Description of Flight Recorders

3.4.2.1 Kanishka was equipped with a Fairchild A-100 Cockpit Voice Recorder Serial No. 5809 and a Lockheed 209E Digital Flight Data Recorder Serial No. 1282. These were each equipped with Dukane Underwater Acoustic Beacons and were installed adjacent to each other in the cabin on the left side near the rear pressure bulkhead.

*3.4.2.2

ICAO Note.— Paragraphs 3.4.1.7 and 3.4.2.2 were not reproduced.

3.4.2.3 The serial digital signal recorded by the DFDR was generated by a Teledyne Flight Data Acquisition Unit installed in the forward electronics bay below the cabin floor. Adjacent to this unit was a Lockheed Model 280 Quick Access Recorder that recorded the same serial digital signals on to a 50 hour cassette.

3.4.2.4 The DFDR records 52 basic parameters on a magnetic tape. The tape preserves records of the last 25 hours. The serial digital signal has a bit rate of 768 bits per second and is recorded at a tape speed of 0.37 inches per second.

*3.4.3 Examination of Flight Recorders and Tapes

3.4.4. Recovery of Information

3.4.4.1 Cockpit Voice Recorder Tape

The spool was removed from the CVR and was washed with distilled water, dried and loaded on to another spool. The cleaned and dried tape was taken to the Bhabha Atomic Research Centre (BARC), and a copy of the tape was prepared which was used for preparing transcript and carrying out further analysis. The transcript of the CVR conversation is given in Appendix 2.

3.4.4.2 Shannon Air Traffic Control Tape

A copy of this tape that contains all radio communications between the aircraft and Shannon was provided to the Indian Authorities by the Air Traffic Control Authorities, Shannon. The recording also included the short series of unusual sounds that occurred about the time of the accident.

3.4.4.3 When the CVR and the ATC tapes were played it was found that some adjustment in speed was necessary so as to synchronize the two. This adjustment was independently carried out by different experts who analysed the CVR tapes.

**ICAO Note.*— Section 3.4.3 was not reproduced.

3.4.4.4 Digitial Flight Data Recorder Tape

The Lockheed representative had brought a Lockheed Model 235 Copy Recorder from his plant. This unit copied all the 25 hours of data from the recorder by running it at high speed for only two passes of the tape, an operation lasting only 16 minutes. A copy tape was made by this procedure before embarking on the standard Air India recovery procedure to serve as a back-up tape in the event of physical damage to the original tape in subsequent playback.

3.4.4.5 Air India playback equipment for the DFDR required that the tape be re-installed in another DFDR in which it was driven at high speed. In the standard playback procedure, the tape was first run to the beginning of Track 1 through 6 sequentially on to a computer tape followed by a repeat of Track 1. The computer tape was then taken to Air India's main computing facility where selected information was printed out in engineering units.

3.4.4.6 The first printouts showed that the accident was recorded on Track 1, as indicated by the latching relays, and suggested a rather abrupt end to the recording. There was a loss in bit synchronization in word 26 of the last Subframe 3 of data that was followed by a normal Subframe 4. Prior to the loss in bit synchronization, all measurements appeared normal. Plans were made to borrow the high speed oscillograph recorder previously used to study the final CVR signals from BARC to examine the end of the recorded serial digital signal in detail.

3.4.4.7 Meanwhile, the critical section of the tape and the heads of the playback recorder were re-cleaned and a second transfer of data on to the computer tape was made. Printouts from this computer tape showed no significant difference from the first one.

3.4.4.8 The recorder was then opened and the tape positioned about 1.5 inches before the final resting place of the tape that was clearly indicated by head imprints on the magnetic oxide coating side. A high speed oscillograph record of a few seconds of data was made and visually decoded. It was found that the recorded GMT was 21 hr 16 min. This time corresponded to 15 min or about 333 inches of the tape after start of the oldest recording downstream of the accident.

3.4.4.9 The tape was then re-positioned using a Lockheed analogue playback unit, that had a display of the recorded time and a stopwatch was used to locate the accident timing. Two oscillograph copies of the end of the serial digital data were made, the second one having more data preceding the end. Visual reading of the traces confirmed that recording became erratic and irrecoverable at the end of Word 26 in Subframe 3 at the recorded time of 07 h : 14m : 35s. The erratic signal continued for about 0.27 inches of the tape before switching back to the data recorded 25 hours earlier.

3.4.4.10 Examination of the printouts confirmed a suspicion that the complete Subframe 4 of data following the partial Subframe 3, was data from 32 seconds earlier that had not been cleared from the data buffer in the computer and that Word 26 of the Subframe 3 was the last normal measurement provided by the recorder.

3.4.4.11 The end of recording occurred at the point on the tape at which some damage had been observed during the cleaning process. It was apparent that, after the end of the recording, the tape had run on for 336 inches before finally coming to rest.

3.4.4.12 A copy tape of the DFDR tape was made at Bombay and taken to Ottawa. Data from the accident flight, the preceeding Toronto-to-Montreal flight and part of the cruise conditions of the earlier flight to Toronto were transcribed on to the computer tape. The tape was edited to minimize errors and converted to engineering units using standards calibration. Time histories of all parameters for periods of interest were plotted. In addition, chart records were made of all parameters in raw data form for the total duration of the last lap of the flight.

3.4.4.13 The DFDR read out shows that the aircraft was cruising at an altitude of 31,000 ft. and a computed air speed of 296 knots till it suddenly stopped recording at 07:14:35 GMT recorded time.

3.4.5 Reports received by the Court

3.4.5.1 The CVR was taken to B.A.R.C. This tape was played by the CVR group a number of times and hard copies of the time information were also prepared using an ultra violet (UV) Recorder. The group consisted of Mr. Regional Controller of Air Safety of D.G.C.A., Mr. of BARC, Mr. of NTSB, USA, Mr. of NTSB, USA and Mr. of CASB, Canada. On 18th July, 1985 this group made the following observations after playing the aforesaid tape (UV recording of CVR is at Fig. 1) :-

"The first visible rising signal volume was observed on channel number three the CAM channel. It reaches a maximum in about 50 milliseconds. At this time noticeable disturbances are observable on the other three channels. A smaller disturbance is observable on channels 2 and 4 earlier than observable on channel 1. A major disturbance is observed to begin approx. ninety milliseconds following the initial observation on channel number 3 (CAM), on channels 1,2 and 4. Following this point at 75 milliseconds the CAM signal subsides to a lower level but much higher than observed ambient (prior to disturbance) where it remains for approximately 375 milliseconds from initiation when it ceases. Channel four goes off at the same time. Channel 1 goes off twenty five milliseconds earlier. Channel two is inconclusive and had a different pattern. All four channels exhibit a disturbance at approx. 45o milliseconds. The cockpit voice recorder power then shuts off at 650 milliseconds.

The Shannon area control centre tape made the night of the accident was examined and printed. It shows a signal was received at approximately the time the aircraft disappeared from radar. It isn't conclusive at this time that the signal originated from the accident aircraft. The signal was received in pulses for approximately five seconds."

3.4.5.2 The tape was again played on 19th July, 1985 and a further report was prepared which was signed by the aforesaid persons and Mr. of NRC, Canada. In this report it was stated as follows:-

"The Shannon area control centre tape was again printed at .05"/ second per inch speed from approximately 22 sec. before the first broadcast from the accident aircraft at 0709.58 until Radio carrier with indecipherable modulation can be heard at 0714:01. The print contains a time encoded signal.

A similar print was made from the CVR channel 4 (Co-Pilot's) of the same audio as received on the ATC tape. Although the tape speed is different, the events when corrected for tape speed errors occur at the same time. It appears that the ATC recording contains the beginning of the aircraft breaking until power is lost to the transmitter since channel one and channel four (Capt + Co-pilot's radio) appear to contain a transmitted signal on the CVR. It is probable that the ATC signal at 0714:01 coincides with the final quarter second of CVR radio channels".

3.4.5.3 On the date i.e. 19th July, 1985, Mr. of NTSB also gave an additional report which is to the following effect :-

"During my observations of numerous cockpit voice recorders I have heard and observed a number of aircraft breakages due to various causes. In this case the explosive sound on the CAM channels occurs prior to any electrical disturbance observable on the selector panel signals. Electrical disturbances can generally be seen prior to audio signal when explosive sounds originate at any significant measureable distance from the microphone (15 feet) and in the area where there is significant electrical systems. It is my opinion that an explosive event occurred close to the cockpit. The CAM signal which follows the explosive event shows a very much higher noise level than cockpit ambient 85 db, indicating to me the cockpit area was penetrated and opened to the atmosphere. The selector panel signals show signatures similar to those of an aircraft breaking up and are apparantly caused by electrical systems disturbance (circuit breaker blowing, fuse switching etc.). The lack of Mayday call and apparent inadvertant signal from the cockpit crew incapacitation. The transmitter coming on due to breakup is phenomena observed previously.

This contains only my personal opinion and in no way should be considered a final determination of cause without corroborating evidence".

3.4.5.4 Copies of the tapes were also sent to some of the participants who wanted to carry out independent analysis.

*3.4.5.5

*3.4.5.6

3.4.6 Court Observations

3.4.6.1 Digital Flight Data Recorder

The reports of Dr. and Mr. which also coincide with the report submitted by Mr. disclose that the DFDR showed no evidence of abnormal values of any of the many parameters being monitored upto a point at which the recorded data signal became irregular for a fraction of a second and recording ceased. Both the DFDR and the CVR stopped at the same time.

3.4.6.2 The short period of irregular digital data that occupied only 0.27 inches of tape, most probably indicates that the recorder was subjected to a sharp angular acceleration in the left wing down sense about the aircraft longitudinal axis.

3.4.6.3 According to Mr. 's report the possibility that the digital recorder was subjected to a sharp disturbance more rapid than violent motion of the aircraft lends some credence to the possibility of a detonation of an explosive device in the aircraft. The other alternative, according to Mr. , which could have led to this was that the Flight Data Acquisition Unit in the main electronics bay or its power supply were suddenly disturbed. As the Lockheed Quick Access Recorder was

*ICAO Note.— Paragraphs 3.4.5.5 and 3.4.5.6 were not reproduced.

not recovered from the wreckage, this possibility could not be investigated further. A perusal of the DFDR print out, however, shows that whereas there was a speed limit of 290 knots (.81 Mach) of the aircraft due to carriage of the 5th pod engine, in actual fact the aircraft's speed during cruise varied from 287 to 296 knots. Mr. asked the Boeing Airplane Company to examine the effect of aircraft cruising at a speed of 296 knots with a 5th pod engine installed on it. The Boeing company sent a reply, inter alia, stating as follows :

> "The operating speed limit of Air India 747-237B, JT9D-7J with fifth engine pod was 290 knots indicated airspeed, with an altitude limit of 35,200 feet. Flight testing of this model airplane configuration was successfully accomplished to a dive speed of 386 knots calibrated airspeed and 0.92 Mach number, with no adverse effects. In the event that the operating speed placard was exceeded an increase in perceptible vibration levels would be felt. As the dive Mach number (0.92) is approached the buffet vibration would increase to level that could become objectional to the flight crew, but would not be hazardous".

3.4.6.4 It would thus be clear that if no adverse effects could have been noticed with a dive speed of 386 knots calibrated airspeed and 0.92 Mach number, there was little likelihbood of the aircraft having been subjected to any adverse effect by reason of the speed varying from 287 to 296 knots while it was cruising at a height of about 31,000 feet.

3.4.6.5 <u>Cockpit Voice Recorder</u>

The Court received four reports of the CVR tape analysis. These reports were of Mr. , Mr. , Mr. and Mr. . Whereas the first three experts appeared and deposed in Court, Mr. did not come.

3.4.6.6. There were certain aspects of the report of Mr. which required clarification. After the Court had failed to secure his presence, it sent a questionnaire to Mr. for his answers thereto.

It is indeed unfortunate that till now no reply has been received. It is in this background that the report dated 13th November, 1985 of Mr. and the reports of other experts have to be judged and analysed.

*3.4.6.7 Mr. Report and Deposition

*3.4.6.12 Mr. Report and Deposition

*3.4.6.19 Mr. Report and Deposition

*3.4.6.36 Mr. Report

3.4.6.49 Court Evaluation

From the reports of all the experts and the testimonies of , and it is clear, and it is agreed to by all of them, that there was a breakup of the aircraft in mid-air. The experts also agreed that the sounds recorded on the ATC Shannon tape at 0714:01 Z emanated from the Kanishka aircraft.

3.4.6.50 Mr. has not said either in the report or in his statement as to what was the cause of the bang. Mr. , on the other hand, is categorical in stating in his report that there was explosive decompression (meaning rapid decompression) on the aircraft. He has, however, stated in the report that there is no evidence of an explosive device. The main reason for his coming to this conclusion is that he had not been able to find low frequencies in the spectra of the CVR of Kanishka. Mr. , on the other hand is equally vehement in concluding that an explosive device had detonated in the front cargo hold of Kanishka.

3.4.6.51 It may be that the frequency spectrum of Kanishka CVR did not contain low frequencies but, as has been admitted by Mr. himself in answer to a Court question, it is not necessary that in the case of every detonation there must necessarily be low frequencies in the spectrum. Frequency spectra of 'Kanishka CVR before 'bang' and

*ICAO Note.— Paragraphs 3.4.6.7 to 3.4.6.48 were not reproduced.

at the 'bang' position are shown in Figs. 2 & 3, indicating presence of additional high frequencies at the bang. Indeed in the casé of Indian Airlines Boeing 737, which admittedly was a case where there was an explosion of a device within about 8 feet of the CAM, the frequency analysis showed absence of low frequencies. Frequency spectrum of Indian Airlines Boeing 737 CVR is shown at Fig. 4. Merely, because therefore, there were no low frequencies present would not mean that there was no detonating device on board the Kanishka. The CVR of Indian Airlines Boeing 737 has not been analysed either by Mr. or Mr. . The analysis was, however, conducted by Mr. and as is evident from his report, there were marked similarities between the spectra of Indian Airlines 737 and Air India's Kanishka CVR. One of the important reasons for coming to this conclusion, which has been indicated by Mr. is the rise time of the bang signal. From the analysis of the Indian Airlines Boeing 737 tape it was observed that it had taken 8 milliseconds for the peak to be reached. It was also seen that the explosive device was approximately 8 feet away from the cockpit area mike. Keeping this in view Mr. observed that in the case of Kanishka the peak of the bang signal was reached in about 40 milliseconds. He, therefore, concluded that the origin of the bang sound was about 40 feet away from the cockpit area mike.

3.4.6.52 It would be pertinent to note that even according to the report of Mr. the rise time in the case of Kanishka, which has been given for the peak is about 40 milliseconds. He, however, does not attach much importance to this because according to him after about 40 ms automatic gain control would become effective.

3.4.6.53 Mr. has no personal experience of the time which it would take for the Automatic Gain Control to take effect. He has got the figures from the manufacturer. Mr. admitted that the time which it will take for the AGC to be effective is not indicated in any published document of the manufacturer.

3.4.6.54 Mr. however, personally carried out the experiments on a Boeing 747 by using an instrument similar to what was on board Kanishka. From the testimony of Mr. it is apparent that the results which he got were different. As per his testimony, for the AGC to be effective it will take 130 ms. If this be so then it may be possible to conclude that in the case of Kanishka the peak was reached in 40 ms. and thereafter the signal decayed and the signal was in no way effected by the AGC.

3.4.6.55 A reference may also be made, at this stage, the frequency spectrum of the sound of the hand gun which was fired on a boeing 737 flight deck. Frequency spectrum prepared by Mr. is shown at Fig. 5. He has stated that the rise time for reaching the peak is almost instantaneous. Same is the case with regard to the frequency spectrum prepared by him of a bomb in a B-737 aircraft where the bomb had been placed in the freight hold which is shown in Fig. 6. A perusal of that spectrum also shows that the peak was reached in approximately 5 ms. The forward freight hold compartment of Boeing 737 is much more than five feet away from the cockpit area mike. If the theory of Mr. was to be applied then as per the frequency analysis of this Boeing 737 bomb, the distance from the area mike could not have been more than 5 ft. It is, however, known, as per the report of that the bomb was actually in the freight hold which would mean not nearer than about 25 feet.

3.4.6.56 From what has been stated in the various reports, as well as in the testimony of the 3 experts who apperared in the Court, the only safe conclusion which can be drawn is that possibly enough study has not been done, due to lack of adequate data, which can lead one to the conclusion as to the exact nature of the sound and the distance from which it originated.

3.4.6.57 The fact that a bang was heard is evident to the ear when the CVR as well as the ATC tapes are played. The bang could have been caused by a rapid decompression but it could also have been caused by an explosive device. One fact which has, however, to be noticed is that the sound from the explosion must necessarily emanate a few milliseconds or seconds earlier than the sound of rapid decompression because the explosion must necessarily occur before a hole is made, which results in decompression. In the event of there being an explosive detonation then the sound from there must reach the area mike first before the sound of decompression is received by it. The sound may travel either through the air or through the structure of the aircraft, but if there is no explosion of a device, but there is nevertheless an explosive decompression for some other reason, then it is that sound which will reach the area mike. To my mind it will be difficult to say, merely by looking at the spectra of the sound, that the bang recorded on the CVR tape was from an explosive device.

3.4.6.58 There are various hypothesis and theories which the experts have to investigate before any acceptable conclusions are arrived at. It so happens that in the present case we have the opinions of four experts, but they do not agree with one another on some material aspects. Two of the experts, namely, Mr. and Mr. are categorical in saying that it is not possible to measure the distance of the origin of the sound on the cockpit area mike, whereas Mr. has come to a different conclusion. Mr. in his report dated 13th November, 1985 in silent on this aspect, though in his earlier report dated 19th July, 1985 he had categorically said that there was an explosive device close to the cockpit.

3.4.6.59 With regard to the nature of the sound also we have 3 different opinions. Mr. is unable to give the nature of the sound, Mr. says it is rapid decompression while Mr. says it is a sound of an explosive device followed by decompression.

3.4.6.60 In the absence of any other technical literature on the subject, it is not possible for this Court to come to the conclusion as to which of the expert is right. The only conclusion which can, however, be arrived at is that the aircraft had broken in midair and that there has been a rapid decompression in the aircraft. Just as it is not possible to say that the spectrum discloses that the bang is due to an explosive device similarly, and as has also been admitted by Mr. and Mr. , it is not possible to say that the bang is due to break up of a structure.

3.4.6.61 The bang could have been due to either of the aforesaid two causes i.e. a bomb explosion or the sound emanating due to rapid decompression. The advantage of carrying out the said analysis is that a number of possible causes of the accident are eliminated. On the other hand, if the analysis is viewed in conjunction with other evidence on the record it is further possible to determine the exact nature or cause of the bang. In the present case the bang, as already noticed, could have been due to the sound originating from the detonation of a device or by reason of rapid decompression. Other evidence on the record, however, clearly indicates that the accident occurred due to a bomb having exploded in the forward cargo hold of Kanishka. The spectra analysis and the conclusions of Mr. are corroborated by other evidence.

TESTS AND RESEARCH

3.5.1 During the course of investigation a number of groups were formed to study and analyse evidence and data which was available. Materials like CVR, ATC and DFDR tapes were also given to the various participants.

3.5.2 The groups as well as other experts studied and analysed the material with them and submitted their reports which have been referred to earlier.

3.5.3 The experts examining the CVR tapes did carry out a number of tests. Different graphs and traces were prepared and the sound was analysed by them. The result of their analysis has been referred to in Chapter 3.4 on Flight Recorders.

3.5.4. The metallurgical examination of some of the recovered pieces was carried out at BARC. The examination of some of the pieces showed different types of damages having been recorded on the targets such as petalling and curling round the holes, spikes etc. The said team carried out certain explosion experiments. Their report on the experiments so carried out has already been set-out in paragraph 3.2 above.

3.5.5 The Indian Air Force has set up an Institute of Aviation Medicine at Bangalore. The Court visited the said Institute on 9th December 1985. During that visit an experiment was conducted in the explosive decompression and high altitude chamber to demonstrate what actually happens during explosive decompression and subsequently on exposure to hypoxia.

3.5.6 Subjects were taken to 8,000 feet in the explosive decompression chamber with oxygen. They were exposed to an altitude of 25,000 feet within one second. During the course of this explosion a loud bang was heard and inside the chamber there was misting and drop in temperature. After this the chamber was allowed to run at 22,000 feet for roughly two minutes and an experiment to show the adverse affects of hypoxia on the subjects was done. In this experiment, subjects were asked to write a given sentence while their oxygen supply was cut off. It was observed that initially the subjects kept on writing the sentence correctly and then after about 120 seconds they started making errors while writing the sentence and finally they stopped writing. At this stage oxygen was re-started and within a few seconds, the subjects started writing their sentence once again. The experiment was completed at this stage and the altitude chamber was brought down to ground level.

3.5.7 The subjects were taken out and were asked questions as to what did they feel. They explained that at the time of explosive decompression, they heard a loud bang, felt cold and saw misting inside the chamber. They also found air escaping from their lungs. On further enquiry about the experiment pertaining to hypoxia, they said that they felt light headed and after that they did not know what happened till they once again noticed that they were writing on a piece of paper.

SECURITY

3.6.1 The evidence and the statements filed on record show that Canadian Security arrangements in place prior to 23rd June, 1985 met the international requirements for civil air transportation. However, before this date, the emphasis was on preventing the boarding of weapons including explosive devices in hand baggage. Hence, the screening of checked baggage was only undertaken in conditions of a heightened threat as was the case with respect to Air India flights.

3.6.2 Air India, as required by Canadian regulation, had a security programme. Because of the threat level assessed against the Airline, Air India had more extensive security measures than almost any other Canadian or international airline. These measures were generally in accordance with the recommended procedures of the ICAO Security Manual for special risk flights. Air India had also requested and had received and arranged for extra security for the month of June, 1985. For Air India flight 181/182, Air India provided a security officer from its New York Office to oversee the security at Toronto and Montreal.

3.6.3 As it became apparent during the course of investigation that security would be an important aspect which would require the attention of the Court, Mr. Director, Facilitation and Security, International Air Transport Association was good enough to appear in Court on 24th January, 1986. His testimony on certain aspects of security was recorded in camera by the Court on that date. The expert evidence has been taken into consideration while formulating some of the recommendations.

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ANALYSIS AND CONCLUSIONS

4.1 From the evidence which is available what has now to be determined is as to what caused the accident.

4.2 Finding the cause of the accident is usually a deduction from known set of facts. In the present case known facts are not very many, but there are a number of possible events which might have happened which could have led to the crash.

4.3 The first task is to try and marshal the facts which may have a bearing as to the cause of the accident.

*ICAO Note.— Section 3.7 (International co-operation) was not reproduced.

4.4 It is undisputed, and there is ample evidence on the record to prove it, that Air India's Kanishka had a normal and uneventful flight out of Montreal. The aircraft had been in air for about five hours and was cruising smoothly at an altitude of 31,000 feet. The readout from the CVR shows that there was no emergency on board till the catastrophic event had occurred. This is corroborated by the printout available from the DFDR. The event occurred at approximately 0714 Z and that brought the aircraft down, and it probably hit the surface of the sea within a distance of 5 miles. The time within which the plane came down at such a steep angle could not have been more than very few minutes. There was a sudden snapping of the communication between the aircraft and the ground. The aircraft had also suddenly disappeared from the radar.

4.5 It is evident that an event had occurred at 31,000 feet which had brought down 'Kanishka'. What could have possibly happened to it? The aircraft was apparently incapacitated and this was due either to it having been hit from outside; or due to some structural failure; or due to the detonation of an explosive device within the aircraft.

4.6 Evidence indicates that after the event had occurred, though the pilots did not or were not in a position to communicate with the ground, they nevertheless appeared to have taken some action. According to Mr. , witness No. 12, the examination of the wreckage showed that spoilers had been deployed and this must have been done with a view to enter into emergency descent. He has further speculated that such an emergency descent would support or perhaps cause a rupture in the forward area or a partial damage to the hydraulic system or damage to the control system which created such a condition that the pilots were not able to control the flight. The wreckage further showed that the jack screw for the stabilizer trim was found in the nose-up position and it was hard to explain how this got there merely as a result of impact with the water. The trim being in that position could only have been due to the pilot selecting it or as a result of a situation created by an explosion. In that position, and at a high aircraft speed, there would have been an extremely high g-loading on the aircraft.

4.7 It can further be speculated that if an explosion takes place in the forward cargo compartment, the oxygen stream might have been damaged so that when the pilots donned their masks as part of the emergency drill for explosive decompression, they were not breathing enriched oxygen and the time of useful consciousness at about 31,000 feet would be significantly less than 30 seconds under high stress and if the pilots became unconscious as a result of this, then the aircraft would have got out of control which would explain the subsequent events.

4.8 None of the participants have produced any evidence which could lead one to the conclusion, that there was any external hit to the aircraft. In fact in the report dated 13th November, 1985, Mr. has stated as follows :

"The United States Norad/Space Command has confirmed that there was no incoming space debris in the vicinity of Ireland on June 23, 1985."

4.9 Thus we are left with only two of the possibilities viz., structural failure or accident having been caused due to a bomb having been placed inside the aircraft.

4.10 After going through the entire record we find that there is circumstantial as well as direct evidence which directly points to the cause of the accident as being that of an explosion of a bomb in the forward cargo hold of the aircraft. At the same time there is complete lack of evidence to indicate that there was any structural failure.

4.11 The circumstantial and direct evidence which leads to the aforesaid conclusion is as follows :

A. Connection with an explosion at Narita Airport :

On 23rd June, 1985 there was an explosion at the Narita Airport. The explosion occurred when a bomb exploded in a suit case which was to be interlined to Air India's Flight No. 301 from Tokyo to Bangkok. The following events, which had occurred prior to this explosion, clearly establish the connection between the two incidents :

(i) On 19 June 1985, at approximately 1800 PDT (0100 GMT, 20 June), a CP Air reservations agent in Vancouver received a telephone call from a male with a slight Indian accent. He identified himself as Mr. Singh and informed the agent that he was making bookings for two different males also with the surname of Singh. One booking was made in the name of Jaswand Singh with CP 086 from Vacouver to Dorval on 22 June 1985 to link with AI 182 departing from Mirabel. The other booking was to Bangkok using CP 003 from Vancouver to Tokyo and AI 301 from Tokyo to Bangkok. This booking was made in the name of Mohinderbel Singh. A local telephone contact number was given and the call lasted about one-half hour.

(ii) On the same date at approxmimately 1920 PDT (0220 GMT), another reservations agent for CP Air was contacted and requested to change the booking for Jaswand Singh. The confirmed flight on CP 086 was cancelled and a reservation was made on CP 060 from Vancouver to Toronto, and a request to be wait-listed on AI 181/182 from Toronto to Delhi was made.

(iii) On 20 June, 1985 at about 1210 PDT (1910 GMT), a male appearing to be of Indian origin purchased the tickets with cash from a CP Air Ticket office in Vancouver. The booking in the name of Mohinderbel Singh was changed to L. Singh and the booking using the name of Jaswand Singh changed to 'M. Singh'. The telephone contact number was also changed. The final itinerary was as follows :

(a) <u>M. Singh</u> - CP 060 Vancouver - Toronto Confirmed Scheduled to depart Vancouver at 0900 PDT, 22 June 1985

- AI 181 Toronto - Montreal Wait-listed Scheduled to depart Toronto at 1835 EDT, 22nd June, 1985
- AI 182 Montreal - Delhi Wait-listed Scheduled to depart Montreal at 2020 EDT, 22nd June, 1985

(b) L. Singh

- CP 003 Vancouver - Tokyo Confirmed Scheduled to depart Vancouver at 1315 PDT, 22 June, 1985
- Air India 301 Tokyo - Bangkok Confirmed Scheduled to depart Tokyo at 1705 time in Tokyo, local 23 June, 1985

(iv) On 22 June, 1985 at about 0630 PDT (1330 GMT), a caller identifying himself as Mr. Manjit Singh called the CP Air reservations office. The caller spoke with a heavy Indian accent and wanted to know if his booking on AI 181/182 was confirmed. The caller was informed by the agent that he was still wait-listed out of Toronto and offered to make alternate arrangements to Delhi. The caller stated that he would rather go to the airport and take his chances. The caller also asked if he could send his luggage from Vancouver to Delhi and was told he could not check his baggage past Toronto unless his flight was confirmed.

(v) On Saturday morning, 22 June, 1985, a CP Air passenger agent worked check-in position number 26 at the CP AIR ticket counter, Vancouver International Airport, and recalls dealing with a passenger of Indian origin booked on CP 060 and then on to Delhi. The passenger stated that he wanted his bag tagged right to Delhi from Vancouver. After checking the computer, the agent explained that since he was not confirmed past Toronto his baggage could not be interlined. The passenger insisted and, as the line-up was long, the agent relented and interlined his suitcase. The flight manifest for CP 060 shows that 'M. Singh' checked in through this passenger agent, was assigned seat 10B, and checked one piece of baggage.

(vi) The flight manifest for CP 003 shows that on the same day the person using the name of 'L. Singh' with an interline ticket to Bangkok also checked through the same counter, was assigned seat 38H, and checked one piece of baggage.

(vii) A check of CP Air's records and interviews with passengers on flights CP 003 and CP 060 indicates that the persons identifying themselves as 'M. Singh' and 'L. Singh' did not board these respective flights.

(viii) In a statement of annexed to the affidavit of Police Officer, City of Toronto, he has stated that on 22nd June, 1985 he was employed as a driver whose responsibility was to deliver interlined baggage between terminal 2 to Terminal 1 and vice versa at Toronto. He has further stated that he had picked up 4 bags from Terminal 1 which were destined for terminal 2 Air India. Three of these bags were from U.S. Air originating from New York city. Regarding the last bag he stated as follows :

> "The fourth bag destined for Air India was, I distinctly remember looking at the baggage tag and it was pink with the CP logo in blue and letters saying CP on it there were also numbers but I can't remember the number, from CP Air and I remember it was from Vancouver. On the bottom of the tag it said vancouver using the initials YVR and the flight number which I can't remember. The bag was destined for India. When I arrived at the CP Air belt there were a number of bags from other airlines on the belt included

in these were the three U.S. Air bags destined for Air India. As I was finishing loading the carts, a CP Air station attendant who had been unloading bags from containers, I noticed as I checked once more for anymore bags, drop another bag on the conveyer belt. This was the bag destined for Air India. It was dark brown Samsonite Hard sided Type 01A on the Baggage Identification Chart. After they were loaded onto the cart I took them over to Air Canada domestic belt at Gate 89-91".

To further questions posed to him, stated that this bag from CP Air weighed approximately 70 lbs and there was something which rattled inside the bag. He could not say what it was but he said that "it sounded small". When specifically asked whether he thought there was something big inside the bag, he answered in the affirmative, and added that he did not know what was in it but it was heavy. There was discrepancy in the time when he is alleged to have picked up the bags which he had indicated in his schedule when compared with CP Air Vancouver flight which had arrived at 1622 hours. When this was pointed out to Long, he answered "I could have may be got the time wrong, it was during the busy period. It could have been an estimate time. But I do remember the bag came off CP air. It could have been 16:34 Hrs. I don't know."

(ix) The aircraft departed from Toronto for Mirabel and London with the suitcase unaccompained by the passenger who had checked it in at Vancouver. Similarly, CP Air 003 departed Toronto for Tokyo with the baggage of one passenger 'L. Singh' to be interlined to Air India flight AI 301 to Bangkok even though 'L Singh' had not boarded that flight.

(x) The linking of the two occurrences namely the blast at Narita Airport and the Air India accident becomes startingly evident if we look at the following chronology of events:

CPA 003 (VANCOUVER-TOKYO) CPA 060 (VANCOUVER-TORONTO)

Connection to Air India 301 — Connecting to Air India 182

WESTBOUND — EASTBOUND

All Times GMT

Thurs
20 June,
1985

0057

A male called C.P. Air Reservations in Vancouver and after discussing a number of routings, booked a one-way ticket and CPA 060 to Toronto with connections to Air India 182 under the name of Jaswand SINGH. A return ticket was also booked on CPA 003 to Tokyo connecting with Air India 301 to Bangkok in the name of Mohinderbel SINGH.

1912

A male attended the CP Air Ticket Office in Vancouver. He paid $ 3005.00 in cash for the above tickets after changing the ticket of Mohinderbel SINGH to L. SINGH and changing from a return to a one-way ticket. He changed the Jaswand SINGH ticket to M. SINGH.

Saturday
22 June

A Mr. SINGH called Reservations and got

1330 confirmation on his one-way ticket to Toronto with luggage to be sent through to India.

1550 M. SINGH checked in with seat 10B confirmed to Toronto. Wanted suitcase interlined to AI 182. Agent relents.

1618 CPA 060 departed Vancouver 18 minutes late. M. SINGH not in assigned seat.

L. SINGH checked in for CPA 003 and one suitcase interlined to Air India 301. Assigned seat 38H.

2022 CPA 060 arrived Toronto 12 minutes late. Some passengers and baggage interlined to AI 181.

2037 CPA 003 departed 17 min. late for Tokyo. L. SINGH not in assigned seat.

	Sunday 23 June	
	0015	Air India 181 departed Toronto for Mirabel 1 hour 40 minutes late.
	0100	Air India arrived Mirabel.
	0218	Air India 182 departed Mirabel 1 hour 38 minutes late.
CPA 003 arrived Narita Airport, Tokyo. Arrived 14 minutes early	0541	
Baggage cart explodes in transit area. 2 killed, 4 injured,	0619	
	0714	Air India 182 disappeared from Radar
Air India 301 departed Narita.	0805	

0815 Air India 182 Scheduled arrival Heathrow (fuel stop).

(xi) It would indeed to too much of a coincidence that two persons, whose tickets were bought at the same time and who had checked in under the names of 'L. Singh' and 'M. Singh' missed their respective flights, more so when 'M. Singh' had insisted at the check in counter at Vancouver that he should be interlined, even though his seat from Toronto on AI 181/182 was not confirmed, and his baggage (one suitcase) accepted and be routed through to Delhi. If there had been some reason for 'gate no-show' by both of them, one would ordinarily have expected both, or at least one of them, to have made efforts, at that time or thereafter, either to ask for refund of money or they should have contacted the airline staff at the Airport and asked that they should be put on another flight.

(xii) A large amount of money had been spent on the purchase of the two tickets and a question which comes to mind is as to why was this money spent if both the tickets were to be wasted and no one was to travel on them, after having checked in and obtained boarding cards. Furthermore, no effort has been made by any of these two persons to try and lodge a claim for the baggage which they had checked in.

(xiii) The aforesaid facts clearly indicate the connection between the travel plans of so called 'L. Singh' and 'M. Singh'. In fact the manner in which the reservations were changed to the names of 'M. Singh' and 'L. Singh' shows the anxiety of some one to hide behind the identity of persons who bore notorious names.

(xiv) The interlined baggage exploded at Narita Airport and there is strong probability that the suticase from Vancouver, which was interlined to AI 182, contained a device similar to the one which had exploded at Narita Airport on 23 June, 1985.

B. CVR and DFDR both stopped simultaneously :

There was simultaneous interruption of electrical power to the flight recorders. The electrical supply could have been interrupted either because of the cables being cut or because of total electric failure. Power supply wires to the CVR and the DFDR run under the passenger cabin ceiling on the left and the right hand side. The supply of electricity through these cables originates from the MEC compartment, which is in front of the forward cargo hold. If the CVR and the DFDR had stopped due to the breakage of electrical supply wires as a result of possible explosion in the aft cargo hold there would have had to be an instantaneous break of almost the entire section of fuselage, because both these recorders had stopped simultaneously. In such a catastrophic event it is not possible that the bottom skin panels of the aft cargo compartment would remain undistorted, or would have no rupture or holes in them. Furthermore, in such an event the tail portion of the aircraft would have been found in the beginning of the wreckage trail, but this was not so. On the other hand, an explosion in the forward cargo compartment would have resulted in damage to the electrical buses located in the MEC and that would, in turn, result in cutting off the electrical power supply causing simultaneous stoppage of the recorders.

C. The ATC Transponder Stopped Transmitting :

The transponder is located at the bottom of the one of the forward rakes immediately forward of the front cargo compartment. Signals from this also stopped being received by the secondary radar at Shannon. Keeping in view that the CVR and the DFDR had stopped simultaneously at about the same time, when the signals from ATC transponder had also ceased, it is reasonable to presume that there must have been a complete breackdown of electrical supply which had affected all the three units. The only event which could have caused such a damage to paralyse the entire MEC compartment could only have been an explosion in the forward cargo hold. It was not possible that any rapid decompression caused by a structural failure could have disrupted the entire electrical power supply from the MEC compartment. In known cases of aircraft being subjected to rapid decompression there has never been such an instantaneous and total stoppage of electrical power and in fact aircraft have been known to have continued to fly and communicate with the ground even after decompression.

D. Non-supply of Oxygen :

Oxygen supply cylinders are located in the ceiling of the forward cargo compartment. Any rupture of the only pipeline which supplies oxygen to the passengers would result in there being no surge of oxygen flow, which alone drops the oxygen masks. The inspection of the wreckage shows that there is no indication of the oxygen masks ever having dropped. A rupture of this pipeline, simultaneously with power rupture, could only have been caused if there had been a detonation of the explosive device in the front cargo hold.

E. Damage in air :

The examination of the floating and the other wreckage shows that the right hand wing leading edge, the No. 3 engine fan cowl, right hand inboard mid flap leading edge and the leading edge of the right hand stabilizer were damaged in flight. This damage could have occurred only if objects had been ejected from the front portion of the aircraft when it was still in the air. The cargo door of the front cargo compartment was also found ruptured from above. This also indicates that the explosion perhaps occurred in the forward cargo compartment causing the objects to come out and thereby damaging the components on the right hand side.

F. Evidence of Overpressurization :

The examination of the structural panels and the other parts of the forward cargo compartment and the aft cargo compartment, recovered from the sea bed, indicates that overpressure condition had occurred in both the cargo compartments. The failure of the passenger cabin floor panels in upward direction also indicates that overpressure was created in both the compartments. It cannot be disputed that whenever an explosive detonates very high pressure shockwaves are formed which travel in all directions and high speed fragments of the container, or the loose material, also move away from the source of explosion. It is, therefore, clear that there was overpressurization in the cargo compartments which resulted in such rupture of the cabin floor panels.

G. Holes in the front cargo hold panels

While the skin panels of the aft cargo compartment are fairly straight and undamaged, the panels of the front cargo compartment are ruptured and have a large number of holes. This shows that there was occurrence of an event in the front cargo compartment and not in the aft cargo compartment.

H. Buckling of Seats :

The seats towards the rear of the aircraft had only the aft legs buckled, whereas the seats towards the front had both the front and the aft legs buckled. This indicated that the whole floor was subjected to a vertical force and was more severe towards the front. Moreover, the upper deck storage cabin was found among floating wreckage. The bottom of this cabin was pushed up in the shape of a dome with no evidence of impact damage. This deformation was indicative of having been caused, possibly, as a result of a shockwave.

I. Metallurgical Examination Results :

A metallurgical examination, especially of Targets 362 and 399, clearly confirms that there was an explosion in the forward cargo compartment. Microscopy around some of the holes discloses that they have such characteristics like twinning which can be present only if the holes had been puntured due to the detonation of an explosive device.

J. CVR Tape Analysis :

The report of CVR tape analysis by Mr. also corroborates the aforesaid evidence i.e. that there was a bomb in the forward cargo hold of the aircraft.

RECOMMENDATIONS

5.1 ICAO, IATA and the States should :-

(a) undertake an ongoing review of established aviation security standards to prevent the placement of explosive substances on board commercial aircraft;

(b) establish a programme of monitoring the implimentation of security measures in airports around the world, in cooperation with the Governments concerned. For each airport studied, it should report its findings and recomend any improvements that may be required;

(c) consider establishing a group of civil aviation experts to investigate serious breaches of security. The purpose of these investigations would be to determine the facts of an incident so that necessary measures could be developed and implemented world wide to prevent similar breaches in the future.

Note : As it may take some time for ICAO and IATA to implement these recommendations, at least those countries which have international air traffic should take up effective measures without delay.

5.2 ICAO should :-

(a) develop a model clause on security that could be used in the bilateral air agreements that govern the exchange of air traffic rights between countries;

(b) consider establishing standards for the training of security personnel.

5.3 IATA should develop practical procedures for reconciliation of interlined passengers and their baggage at intermediate airports.

5.4 Interlining of checked-in baggage should not be done if a passenger does not have a confirmed reservation on the onward carrier flight.

5.5 The baggage of interlined passengers should be matched with passengers by the onward carriers before loading the baggage on the aircraft.

5.6 Whenever a Government becomes aware of particular high risk security threat it should notify not only the airline at risk, but also all connecting airlines in order that extra precaution can be taken at potential points of introduction of interline baggage into the system.

5.7 When an airline is aware of a high security threat it should communicate the same to the host state as well as, if possible and prudent, to the other airlines operating there.

5.8 Passenger count should be done at boarding gate and in case of 'no gate show' of a passenger, his baggage must be off-loaded.

5.9 All checked-in baggage, whether it has been screened by X-ray machine or not, should be personally matched and identified with the passengers boarding an aircraft. Any baggage which is not so identified should be off-loaded. This is advisable as examination of the baggage with the help of an X-ray machine has its own limitations and is not fool proof. Some explosives hidden in radios, cameras etc. may not be readily detected by such a machine. In fact an explosive not placed in a metallic container will not be detectable by an X-ray machine. Similarly, a plastic explosive can be given an innocuous shape or form so as to avoid detection by an X-Ray. Reliance on an X-Ray machine alone may in fact provide a false sense of security.

5.10 Effectiveness of the instrument known as PD-4 is highly questionable. It is not advisable to rely on it.

5.11 All unaccompanied baggage should be placed on the aircraft after their contents have been physically checked. In the alternative, it should be loaded only after it has been placed in a decompression chamber and the host state is satisfied that the baggage is clean and the shipper has been identified.

5.12 Airlines should have effective backup security equipment or procedures available in case of mechanical break down of security equipment.

5.13 All hand baggage, including that of the crew, should be opened and the contents physically checked even if the said baggage has been x-rayed. This will no doubt be a bit time consuming and laborius but if security is to be meaningful, then slight inconvenience has to be endured in order to ensure a safer flight.

5.14 The manufacturers of aircraft should take effective steps for protecting sensitive parts of the aircraft from explosive damage.

5.15 Studies should be undertaken to determine the feasibility of physically separating the avionics bay and emergency oxygen systems from the cargo area in aircraft so that these sensitive and essential areas of the aircraft cannot be damaged or destroyed by a relatively small explosive device concealed in luggage.

5.16 The seats should have safety belts which can act as restraint for the upper part of the body e.g. like a shoulder harness with inertial restraint.

5.17 The seats in the aircraft should be so designed so as to incorporate shock absorbing systems within the seat and they should be manufactured by using material which does not break easily.

5.18 In addition to the cockpit voice recorder, there should be in the cockpit a video/scanning camera which would record the movements and the audio sounds in the cockpit. This will not only assist in ascertaining as to how the pilots act during as emergency but, in the case of hijacking, would also assist in the identification of the hijackers.

5.19 The CVR should record all the conservation and sounds in the cockpit for the entire duration of the flight, and not merely for the last 30 minutes.

5.20 The CVR and the DFDR should be powered from two alternative sources of energy.

5.21 The oxygen for the flight crew should be supplied from two different sources i.e. in the event of an emergency the pilot and the co-pilot must don the oxygen mask and the oxygen must be supplied from different source.

5.22 Suitable provisions should be incorporated in Annex 13 which would give power to an Investigator to record evidence outside the country of investigation and also to summon witness from abroad. It should also be mandatory on the contracting States to give information sought for by an Investigator.

ICAO Note.— Names of personnel were deleted. Minor editorial changes were made. Chapter 1, Sections 3.2.3, 3.2.4, 3.2.8, paragraphs 3.2.10.4, 3.2.10.6, 3.2.10.8, 3.2.10.10, 3.2.10.11, 3.2.10.14 to 3.2.10.16, 3.2.11.5, 3.4.1.7, 3.4.2.2, Section 3.4.3, paragraphs 3.4.5.5, 3.4.5.6, 3.4.6.7 to 3.4.6.48 and Section 3.7 were not reproduced. Appendices were not reproduced.

ICAO Ref.: 148/85

No. 5

Lockheed L-1011-385-1, N726DA, accident at Dallas/Fort Worth, United States, on 2 August 1985. Report No. NTSB/AAR-86/05 released by the National Transportation Safety Board, United States

SYNOPSIS

On August 2, 1985, at 1805:52 central daylight time, Delta Air Lines flight 191, a Lockheed L-1011-385-1, N726DA, crashed while approaching to land on runway 17L at the Dallas/Fort Worth International Airport, Texas. While passing through the rain shaft beneath a thunderstorm, flight 191 entered a microburst which the pilot was unable to traverse successfully. The airplane struck the ground about 6,300 feet north of the approach end of runway 17L, hit a car on a highway north of the runway killing the driver, struck two water tanks on the airport, and broke apart. Except for a section of the airplane containing the aft fuselage and empennage, the remainder of the airplane disintegrated during the impact sequence, and a severe fire erupted during the impact sequence. Of the 163 persons aboard, 134 passengers and crewmembers were killed; 26 passengers and 3 cabin attendants survived.

The National Transportation Safety Board determines that the probable causes of the accident were the flightcrew's decision to initiate and continue the approach into a cumulonimbus cloud which they observed to contain visible lightning; the lack of specific guidelines, procedures, and training for avoiding and escaping from low-altitude windshear; and the lack of definitive, real-time windshear hazard information. This resulted in the aircraft's encounter at low altitude with a microburst-induced, severe windshear from a rapidly developing thunderstorm located on the final approach course.

1. FACTUAL INFORMATION

1.1 History of the Flight

On August 2, 1985, Delta Air Lines (Delta) flight 191 was a regularly scheduled passenger flight between Fort Lauderdale, Florida, and Los Angeles, California, with an en route stop at the Dallas/Fort Worth International Airport, Texas (DFW Airport). Flight 191, a Lockheed L-1011-385-1 airplane, departed Fort Lauderdale on an instrument flight rules (IFR) flight plan with 152 passengers and a crew of 11 on board at 1510 eastern daylight time. The DFW Airport terminal weather forecast contained in the flightcrew's dispatch document package stated, in part, that there was a possibility of widely scattered rain showers and thunderstorms, becoming isolated after 2000 central daylight time. 1/ The dispatch package also contained company Metro Alert No. T87, valid to 2100, which stated that "an area of isolated thunderstorms is expected over Oklahoma and northern and northeastern Texas . . . a few isolated tops to above

1/ All times herein are central daylight based on the 24-hour clock.

FL 450." 2/ The flightcrew had reviewed this data before takeoff and did not call Delta's weather facility in Atlanta, Georgia, for any additional weather information.

The flight was uneventful until passing New Orleans, Louisiana. A line of weather along the Texas-Louisiana gulf coast had intensified. The flightcrew elected to change their route of flight to the more northerly Blue Ridge arrival route to avoid the developing weather to the south. This change necessitated a 10- to 15-minute hold at the Texarkana, Arkansas, VORTAC 3/ for arrival sequencing at the DFW Airport.

At 1735:26, the airplane's cockpit voice recorder (CVR) showed that the flightcrew received the following Automatic Terminal Information Service (ATIS) 4/ broadcast:

> DFW arrival information romeo, two one four seven Greenwich, weather six thousand scattered, two one thousand scattered, visibility one zero, temperature one zero one, dew point six seven, wind calm, altimeter two niner niner two, runway one eight right one seven left, visual approaches in progress, advise approach control that you have romeo.

At 1735:33, Fort Worth Air Route Traffic Control Center (ARTCC) cleared flight 191 to the Blue Ridge, Texas, VORTAC for the Blue Ridge Nine arrival, 5/ and to begin its descent.

At 1743:45, Fort Worth ARTCC cleared flight 191 to descend to 10,000 feet, 6/ gave it a 29.92 in Hg altimeter setting, and suggested that the flight turn to a heading of 250° "to join the Blue Ridge zero one zero radial inbound and we have a good area there to go through." The captain replied 7/ that he was looking at a "pretty good size" weather cell, "at a heading of two five five . . . and I'd rather not go through it, I'd rather go around it one way or the other." Fort Worth ARTCC then gave the flight another heading and stated "when I can I'll turn you into Blue Ridge, it'll be about the zero one zero radial." At 1746:50, the center cleared flight 191 direct to Blue Ridge and to descend to 9,000 feet, and flight 191 acknowledged receipt of the clearance.

At 1748:22, the captain told the first officer, "You're in good shape. I'm glad we didn't have to go through that mess. I thought sure he was going to send us through it." At 1751:19, the flight engineer said, "Looks like it's raining over Fort Worth." At 1751:42, Forth Worth ARTCC instructed flight 191 to contact DFW Airport Approach Control (Regional Approach Control), and at 1752:08, the flight contacted approach control stating that it was descending through 11,000 feet and had received ATIS Information Romeo. At 1756:28, Regional Approach Control's Feeder East controller transmitted an all aircraft message which was received by flight 191. The message stated in part,

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2/ A level of constant atmospheric pressure related to a reference datum of 29.92 in Hg. Each flight level is stated in three digits that represent hundreds of feet. FL 450 represents a barometric altimeter reading of 45,000 feet.

3/ VORTAC--A collocated very high frequency omni range station and ultra-high frequency tactical air navigational aid providing azimuth and distance information to the user.

4/ ATIS--A continuous broadcast of recorded weather and noncontrol airport information.

5/ A published Standard Arrival Route (STAR).

6/ All altitudes herein are mean sea level unless otherwise specified.

7/ Identification of the crewmembers speaking was made by members of the Cockpit Voice Recorder (CVR) Group familiar with the flightcrew.

"Attention, all aircraft listening . . . there's a little rainshower just north of the airport and they're starting to make ILS [instrument landing system] approaches . . . tune up one oh nine one for one seven left."

At 1759:47, the first officer stated, "We're gonna get our airplane washed," and at 1759:54, the captain switched to Regional Approach Control's Arrival Radar-1 (AR-1) frequency and told the controller that they were at 5,000 feet. AT 1800:36, the approach controller asked American Air Lines flight 351 if it was able to see the airport. (Flight 351 was two airplanes ahead of flight 191 in the landing sequence for runway 17L.) Flight 351 replied, "As soon as we break out of this rainshower we will." The controller then told flight 351 that it was 4 miles from the outer marker, and to join the localizer at 2,300 feet; the controller then cleared the flight for the ILS approach to runway 17L. All of the transmissions between the controller and flight 351 were recorded on flight 191's CVR.

At 1800:51, the approach controller asked flight 191 to reduce its airspeed to 170 knots indicated (KIAS), and to turn left to 270°; flight 191 then acknowledged receipt of the clearance. Flight 191 had been sequenced behind a Learjet Model 25 (Lear 25) for landing on runway 17L.

At 1802:35, the approach controller told flight 191 that it was 6 miles from the outer marker, requested that it turn to 180° to join the localizer at or above 2,300 feet, and stated, "cleared for ILS one seven left approach." The flight acknowledged receipt of the transmission. At 1803:03, the approach controller requested flight 191 "to reduce your speed to one six zero please," and the captain replied, "Be glad to." Thereafter, at 1803:30, he broadcast, "And we're getting some variable winds out there due to a shower . . . out there north end of DFW." This transmission was received by flight 191, and at 1803:34, the CVR's cockpit area microphone (CAM) showed that an unidentified flightcrew member remarked, "Stuff is moving in."

At 1803:46, the approach controller requested flight 191 to slow to 150 KIAS, and to contact the DFW Airport tower. At 1803:58, the captain, after switching to the tower's radio frequency, stated, "Tower, Delta one ninety one heavy, out here in the rain, feels good." The tower cleared the flight to land and informed it, "wind zero nine zero at five, gusts to one five." At 1804:07, the first officer called for the before-landing check. The flightcrew confirmed that the landing gear was down and that the flaps were extended to 33°, the landing flap setting.

At 1804:18, the first officer said, "Lightning coming out of that one." The captain asked, "What," and the first officer repeated "Lightning coming out of that one." The captain asked, "Where," and at 1804:23, the first officer replied, "Right ahead of us."

Flight 191 continued descending along the final approach course. At 1805:05 the captain called out "1,000 feet." At 1805:19, the captain cautioned the first officer to watch his indicated airspeed and a sound identified as rain began. At 1805:21, the captain warned the first officer, "You're gonna lose it all of a sudden, there it is." At 1805:26 the captain stated, "Push it up, push it way up." At 1805:29, the sound of engines at high rpm was heard on the CVR, and the captain said "That's it."

At 1805:44, the Ground Proximity Warning System's (GPWS) 8/ "Whoop whoop pull up" alert sounded and the captain commanded "TOGA". 9/ At 1805:48 and 1805:49, two more GPWS alerts were recorded. At 1805:52 a sound similar to that produced by a landing airplane and the sound of the takeoff warning horn 10/ were recorded. At

1805:56, the local controller in the tower told flight 191 to "go around," and the CVR recording ended at 1805:58.

Witnesses on or near State Highway 114 north of the airport saw flight 191 emerge from the rain about 1.25 miles from the end of runway 17L and then strike an automobile in the westbound lane of State Highway 114. Subsequent investigation showed that the airplane had touched down earlier and became airborne again before striking the automobile.

The local controller handling flight 191 also saw it emerge from the rain at the north end of the field. He testified that,

> When Delta came out of the rain shower his attitude to me did not appear to be safe. As many aircraft as I've seen land in my years at DFW, normal attitude is nose slightly up . . . and when he appeared out of the rain he was in what appeared to be straight and level flight. It just didn't look right to me. (So I told the flight) just, 'Delta go around.' "

After the plane struck the car and a light pole on the highway, other witnesses saw fire on the left side of the airplane in the vicinity of the wing root. The witnesses generally agreed that the airplane struck the ground in a left-wing-low attitude, and that the fuselage rotated counterclockwise after the left wing and cockpit area struck a water tank on the airport. (See figures 1 and 2.) A large explosion obscured the witnesses' view momentarily, and then the tail section emerged from the fireball, skidding backwards. The tail section finally came to rest on its left side with the empennage pointing south and was subsequently blown to an upright position by wind gusts. One hundred and thirty-four persons on board the airplane and the driver of the automobile which was struck by the airplane were killed in the accident; 27 persons on board the airplane and 1 rescue worker at the accident site were injured, 2 passengers on the airplane were uninjured.

The accident occurred at 1805:52 during daylight hours at coordinates 32° 55'N latitude and 97°01'W longitude.

8/ The GPWS warns the flightcrew of a potentially dangerous flight path relative to the ground. The following abnormal flight conditions will produce a "Pull Up" warning: an excessive sink rate below 2,500 feet above the ground (AGL); excessive closure rate toward rising terrain; descent immediately after takeoff; not in landing configuration below 500 feet AGL; and excessive deviation below the ILS glide slope.

9/ TOGA - Takeoff/Go Around Switch. A pilot-actuated switch which, when selected and the airplane is being flown manually, provides flight director command bar guidance for an optimum climbout maneuver.

10/ A throttle-actuated warning system: If flaps, speed brakes, or stabilizer trim are not set correctly for takeoff, the takeoff warning horn will sound when the throttles are advanced. The same horn sounds on the ground if an elevator jam is detected and the throttles are retarded. When airborne, with gear and flaps up and below 180 KIAS, the system will provide an aural warning when the throttles are retarded to flight idle.

1.2 Injuries to Persons

Injuries 11/	Crew	Passengers	Others
Fatal	8	126	1*
Serious	1	14**	0
Minor	2	10	1***
None	0	2	0
Total	11	152	2

* Driver of the automobile struck by flight 191.
** Two survivors died more than 30 days after the accident.
*** An employee of an airline who assisted in rescuing survivors was hospitalized overnight for chest and arm pains.

1.3 Damage to the Airplane

The airplane was destroyed by impact and postcrash fire.

1.4 Other Damage

One automobile was destroyed, four highway light standards were knocked over, and two water storage tanks on the airport were damaged. The north water tank was dented and the south tank was buckled and displaced from its base.

1.5 Personnel Information

The flightcrew, cabin crew, and air traffic controllers were qualified in accordance with current regulations. The examination of the training records of all personnel did not reveal derogatory entries or anything unusual. (See appendix B.)

The investigation of the background of the flightcrew and their activities during the 2 to 3 days before reporting for the accident flight did not reveal anything remarkable. According to airmen who had flown with the captain, he was a very capable and meticulous pilot who adhered strictly to company procedures, explained his thoughts about airplane operation to the flightcrew, and cautiously deviated around thunderstorms even if other flights took more direct routes. He willingly accepted suggestions from his flightcrew and made prompt decisions. The captain's personnel file showed that he had been designated by the Federal Aviation Administration (FAA) to serve as a line check airman in the Boeing 727 and McDonnell Douglas DC-8 airplanes.

FAA surveillance records indicate that the captain had received eight en route inspections in the L-1011 since 1979, and all were satisfactory with favorable comments added concerning cockpit discipline and standardization.

11/ Section 49 CFR 830.2 of the Safety Board's rules defines a "fatality" and a "serious injury" as follows: "Fatal Injury" means any injury which results in death within 30 days of the accident. "Serious injury" means any injury which (1) requires hospitalization for more than 48 hours, commencing within 7 days from the date the injury was received; (2) results in a fracture of any bone (except simple fractures of fingers, toes, or nose); (3) causes severe hemorrhages, nerve, muscle, or tendon damage; (4) involves any internal organ; or (5) involves second- or third-degree burns, or any burns affecting more than 5 percent of the body surface.

Delta captains who had flown recently with the first officer described him as an above average first officer. They stated that he had excellent knowledge of the L-1011. For 2 years, beginning in September 1977, the first officer had worked with the company's L-1011 ground school instructors staff to revise completely Books I and II of the Delta Air Lines L-1011 Pilot Operating Manual. In October 1973, the FAA designated the first officer as a line and proficiency check airman in the L-1011 airplane.

Fellow company cockpit personnel described the second officer as observant, alert, and professional. He monitored the operation of the airplane and called attention to items he thought required it. He had a good knowledge of the airplane. He had served as second officer instructor and check airman on the Boeing B-727 airplane. FAA records for eight route inspections since April 1981 indicated satisfactory performance.

Interviews with the three air traffic control (ATC) controllers who had provided air traffic services to flight 191 during its descent and final approach to DFW Airport did not disclose anything either remarkable or out of the ordinary. The three controllers, two radar controllers, and local controller in the airport tower were full performance level (FPL) controllers and were fully qualified to staff their respective positions. (See appendix B.) Only one controller, the AR-1 controller had worked any overtime during the 2 weeks preceding the accident. He had worked overtime on July 30, 1986, and was off duty the following day.

1.6 Airplane Information

The airplane, a Lockheed L-1011-385-1, N726DA, was owned and operated by Delta. (See appendix C.) The airplane's maximum takeoff and landing gross weights were 430,000 pounds and 348,000 pounds, respectively. Based on the company's final weight data record contained in flight 191's dispatch documents, its estimated landing weight and center of gravity for landing at the DFW Airport were 324,800 pounds and 21.8 percent MAC (mean aerodynamic chord). The forward and aft center of gravity limits for landing were 17.1 percent MAC and 32.4 percent MAC. Based on the landing weight and with the flaps set at 33°, the calculated approach speed was 137 KIAS. 12/ The maximum allowable tailwind for takeoff and landing was 10 knots, and the maximum demonstrated landing crosswind was 35 knots.

Flight 191 had about 28,000 pounds of fuel when it began its approach. According to the flight plan, 12,300 pounds plus the required 11,000-pound reserve were required for the flight to the alternate airport, San Antonio, Texas, leaving 4,700 pounds of fuel for maneuvering in the DFW Airport area. At 3,000 feet, gear and flaps up, 4,700 pounds of fuel would have permitted the flight to hold about 20 minutes before departing for San Antonio.

N726DA was equipped with a Bendix model RDR-1F monochromatic weather radar system. The system operates on X-band frequency at a 3.2 cm wavelength. The system is designed to display targets at three range selections--50, 150, and 300 nautical miles (nmi)--and to display weather in two modes--normal and contour. In the normal mode, any precipitation return exceeding a radar reflectivity of 20 dBZ 13/ is displayed as a luminescent green area on the dark background of the plan position indicator (PPI). The stronger the reflectivity of the precipitation return, the stronger the return displayed on the PPI will be. When the radar system is placed in contour mode, the contour circuitry,

12/ Approach, or reference speed (Vref), is a speed equal to 1.3 times the stall speed in a particular airplane configuration.
13/ dBZ: A measurement of radar reflectivity expressed in decibels.

in effect, inverts all levels of reflectivity above 40 dBZ and displays them as a black hole surrounded by luminescent green areas. The 40-dBZ reflectivity level corresponds approximately to a National Weather Service (NWS) level 3 radar echo (see section 1.7).

The display area of the PPI is about 3 1/2 inches in diameter. With a 50-nmi range selection, a weather cell with a diameter of 10 to 15 nmi would cover a diameter of 0.6 to 0.9 inch on the PPI. If the precipitation contained in the cell exceeded a 40-dBZ reflectivity, and the pilot selected contour mode, that part of the cell exceeding the 40-dBZ level would contour and appear as a black hole on the PPI. As the range between the airplane and the cell decreased, the dimensions of the cell portrayal would remain constant, but the portrayal would move downward toward the origin point of the antenna sweep at the bottom center of the PPI. If ground returns were being displayed on the PPI as the airplane approached the cell, the pilot would have to increase the antenna tilt until the ground returns were eliminated. As the airplane closed to within 2 nmi of the cell, the cell's radar return would begin to disappear at the base of the PPI.

The airplane's logbook showed that flightcrews had written up the weather radar system seven times between June 6 and July 25, 1985. The logbook entries also showed that corrective action had been accomplished after each flightcrew entry. After July 25, no further entries concerning the weather radar were found nor were any carry-over maintenance items on this system found.

1.7 Meteorological Information

The 1600 NWS surface analysis weather chart issued by the National Meteorological Center, Camp Springs, Maryland, showed a weak diffuse stationary front about 60 nmi north of the DFW Airport. The 1900 NWS surface analysis chart also showed a weak diffuse cold front about 60 nmi north of the DFW Airport.

The NWS terminal forecast for the DFW Airport pertinent to the accident indicated a slight chance of a thunderstorm with a moderate rain shower. The NWS area forecast pertinent to the accident called for isolated thunderstorms with moderate rain showers for northern and eastern portions of Texas. The terminal forecast was issued by the NWS Forecast Office in Fort Worth, Texas, and the area forecast was issued by the National Aviation Weather Advisory Unit in Kansas City, Missouri.

There were no SIGMETS, 14/ convective SIGMETs 15/, Severe Weather Warnings, Local Aviation Warnings, Severe Weather Watches, or Center Weather Advisories (CWA) in effect for the time and area of the accident.

The company's dispatch and meteorology department provided the flightcrew with a dispatch package which contained the following weather documents: the weather at DFW Airport and at the flight's field alternate, San Antonio; a DFW Airport terminal weather forecast indicating widely scattered moderate rain showers and thunderstorms with moderate rain showers; an en route forecast indicating isolated thunderstorms, moderate rain showers over Oklahoma and northern and northeastern Texas with a few isolated tops above 45,000 feet; and Delta Metro Alerts applicable to the route of flight. The forecasts were prepared by Delta meteorologists.

14/ A weather advisory concerning weather significant to the safety of all aircraft.
15/ Convective SIGMETs are issued by the National Aviation Weather Advisory Unit, Kansas City, Missouri, for lines of thunderstorms, severe/embedded thunderstorms of any intensity level, and for areas of 3,000 square miles or larger with VIP level 4 (see section 1.7.1) or greater covering at least 40 percent of the area.

1.7.1 Weather Radar Data

The weather radar antenna at the NWS station at Stephenville, Texas, is located about 72 nmi from the approach end of runway 17L at DFW Airport on a bearing of 55°. The Stephenville radar is a Weather Surveillance Radar (WSR) type 57M with Video Integrator Processor (VIP) equipment. The VIP equipment permits NWS radar observers to determine objectively the intensities of radar weather echoes. Based on this capability, the NWS has classified six levels of echo intensity and has assigned VIP numbers for each level. (See table 1.)

Table 1.--VIP levels and categories of intensity and rainfall rate.

VIP level	Echo intensity	Convective rainfall rate (in/hr)	dBZ (threshold values)
1	weak	0.05 - 0.2	30
2	moderate	0.20 - 1.1	30
3	strong	1.10 - 2.2	41
4	very strong	2.20 - 4.5	46
5	intense	4.50 - 7.1	50
6	extreme	>7.1	57

Although existing NWS weather radar systems cannot detect turbulence, there is a correlation between the degree of turbulence and other weather features associated with thunderstorms and the intensity of the radar weather echo. The degree of turbulence and type of weather phenomena associated with these VIP levels have been identified and categorized. The resultant tabular data has been made available to pilots and controllers in various publications. The following table, excerpted from the Pilot/Controller Glossary of the June 6, 1985, Airmans Information Manual (AIM), presents the weather features likely to be associated with the VIP levels during thunderstorm weather situations.

Table 2.--Radar weather echo intensity levels.

1. Level 1 (WEAK) and Level 2 (MODERATE). Light to moderate turbulence is possible with lightning.
2. Level 3 (STRONG). Severe turbulence possible, lightning.
3. Level 4 (VERY STRONG). Severe turbulence likely, lightning.
4. Level 5 (INTENSE). Severe turbulence, lightning, organized wind gusts. Hail likely.
5. Level 6 (EXTREME). Severe turbulence, large hail, lightning, and extensive wind gusts.

Photographs taken of the Stephenville weather radar display were examined by a NWS Southern Region Radar Program Leader. The photographs were taken at 4- to 5-minute intervals between 1728 and 1813 and the program leader's examination revealed the following:

Between 1728 and 1743, two small pinpoint radar echoes appeared about 9 to 10 nmi northeast of the end of runway 17L; however, these two echoes disappeared by 1743.

At 1748, a VIP level 2 cell, hereinafter called Cell "C," developed about 6 nmi northeast of the end of runway 17L. By 1752, Cell "C" had intensified to a VIP level 3, and a new pinpoint radar echo, hereinafter called Cell "D," had developed south of Cell "C". Cell "D" was located about 2 nmi northeast of the end of runway 17L and its intensity was about VIP level 1.

At 1756, Cell "D" had intensified to about VIP level 3 and was located just north of the end of runway 17L. Cell "C" had not moved and its intensity "was not discernible."

At 1800, Cell "D," which appeared to be "the dominant echo," was still located near the end of runway 17L, and "appeared to be a VIP level 3." Cell "C" was "no longer displayed." By 1804, Cell "D" had intensified to a VIP level 4.

Stephenville Upper Air Radar Specialist.--The upper air radar specialist on duty at the time of the accident testified that he left his radar position about 1735 for dinner. The room in which he ate was equipped with a television monitor which displays the weather echo intensity from the Stephenville weather radar. The monitor uses different colors to portray the six VIP intensity levels. The radar specialist testified that he was able to and did monitor the presentation while he was eating.

At 1748, the radar specialist finished eating, but he did not return to the radarscope. Instead he tended to other duties and assisted another station specialist in preparing and launching a radiosonde ascent. 16/

About 1800, the radar specialist returned to the radar and saw a small weather cell (previously identified as Cell "D"). The top of the cell was 40,000 feet, and after measuring its intensity with the VIP equipment, the radar specialist testified that it was a "pinpoint four." He testified, "A pinpoint four means [that the cell was] barely a four intensity."

The radar specialist testified that Cell "D" was "in the area of [the airport]," but he could not state a precise distance. The weather radar did not have an internal map overlay, and in order to determine prominent geographical features, he had to put a paper overlay or a transparency on the [radar] scope." While the overlay used by the radar specialist included Dallas, Fort Worth, and other communities in the area, it did not include DFW Airport or other airports.

About 1804, the radar specialist called the Fort Worth Forecast Office, advised it of the presence of Cell "D," that it was a very strong echo, that the top was at 40,000 feet, and that he had observed the upper structure of the cell and had not found any severe weather in it (i.e., the cell's mid-level reflectivity was not equal to or greater than VIP level 4 and there was no mid-level overhang).

The radar specialist was not a meteorologist and was not qualified to issue either a forecast or a prediction as to whether Cell "D" would either dissipate or continue growing. He was not required to notify anyone when a thunderstorm was located near

16/ An instrument sent aloft to measure temperature, pressure, and humidity. Wind speed and direction information are obtained by tracking the radiosonde.

DFW Airport, nor was he required to notify either the Fort Worth ARTCC's Center Weather Service Unit or anyone at DFW Airport.

After notifying the Fort Worth Forecast Office, the radar specialist turned his attention to analyzing other radar echoes on his scope and did not redirect his attention to Cell "D" until about 1821. By that time, the top of Cell "D" had reached 50,000 feet and its intensity had increased to VIP level 5.

The radar specialist also testified that there was another small weather cell just north of Cell "D." He testified that it was hard to estimate the intensity level of the cell based on interpretation of the radar photographs portraying the cell, but based on the radar photograph taken at 1800, he said that "it looks like maybe a VIP [level] two." The radar specialist testified that, based on the radar photographs, he could not state that the clouds and rains of the small cell (Cell "C") would have masked the thunderstorm represented by Cell "D" from an airplane approaching DFW Airport from the north.

1.7.2 The Fort Worth NWS Forecast Office

The Fort Worth Forecast Office serves both the general public and the aviation community. At the time of the accident, the forecaster-in-charge of the office was also manning the aviation desk. The forecaster-in-charge testified that no special training "with regard to aviation" was required before being assigned to the aviation desk. He testified that it was called the aviation desk because the forecaster assigned to it handled "all aviation products: the terminal forecasts [and] the transcribed weather broadcasts."

The Fort Worth Forecast Office also was responsible for issuing Aviation Weather Warnings to the DFW Airport, and except for Carswell Air Force Base, to all airports in the Dallas/Fort Worth metropolitan area. Pursuant to a local letter of agreement between the forecast office and DFW Airport, the criteria for issuing an Aviation Weather Warning were a sustained wind of 35 knots or greater (1 minute), wind gusts of 40 knots or greater, and a severe thunderstorm/tornado warning for Tarrant and/or Dallas County.

According to the NWS forecaster-in-charge, terminal forecasts and Aviation Weather Warnings are transmitted from the forecast office to DFW Airport through their computer system. The computer data are transmitted to the contract weather observer's office on the airport. The contract weather observer in turn transcribes the data onto an electrowriter system which has terminals in the DFW Airport Tower, Delta Air Lines Operations, and other aviation organizations at DFW Airport. The forecaster-in-charge estimated that the time between the decision to issue an Aviation Weather Warning and its delivery to user organizations at the airport could vary from 6 to 10 minutes. He also testified that there was a dedicated or hot-line telephone between his office and the Center Weather Service Unit in the Fort Worth ARTCC but not to the DFW Airport Tower.

The Fort Worth Forecast Office also had a television monitor which was set to the Stephenville weather radar on the day of the accident. The monitor did not have any mapping capability and the overlays used by the forecasters to fix the geographical location of weather echoes did not depict DFW Airport. Nevertheless, the forecaster-in-charge testified that the meteorologists in the office could fix the location of the airport within 3 miles. According to the forecaster-in-charge, he did not see any weather echoes within 10 nmi of the DFW Airport on the Kavouras monitor until about 1750 or shortly thereafter.

The forecaster-in-charge testified that because the phone call from the Stephenville radar specialist at about 1804 was taken on the speaker by the public forecaster, the forecaster-in-charge overheard the radar specialist describe Cell "D" as a VIP level 4 weather echo with tops at 40,000 feet. The forecaster testified that he observed the cell on the television monitor. He estimated that it was a VIP level 3 to VIP level 4, but that he did not believe it was a storm of sufficient intensity to warrant issuing an Aviation Weather Warning.

According to the forecaster-in-charge, the intensity level of a weather echo "is merely an indication" of the severity of a storm. The forecaster testified, "Once we get a signature on the radar that suggests the possibility, we then seek ground truth." 17/According to the forecaster, in the absence of ground truth reports from observers attesting to the presence of either thunder, hail, or both, he would not label a VIP level 4 cell a thunderstorm. 18/ He also testified that either when or shortly after they received the telephone call from Stephenville, the forecast office began contacting their spotters in the area of Cell "D" for ground truth reports.

The forecaster-in-charge testified that if he observed a VIP level 5 or VIP level 6 echo out over a relatively thinly populated or uninhabited area, and the echo had increased rapidly over the past 20 minutes to 30 minutes, and if "it's moving toward a densely populated area, I would in all likelihood put out a warning on it." He further testified that if he were to observe a VIP level 4 echo moving toward the DFW Airport, "in all likelihood, I would do nothing with it." He testified that throughout the afternoon and early evening hours the meteorologists in the forecast office had observed a number of radar echoes similar to that of Cell "D," none of which had, based on ground truth reports, contained phenomena that met the criteria for issuing a warning to the DFW Airport. Cell "D" did not, in his judgment, seem any different from those cells observed earlier, and therefore he did not issue an Aviation Weather Warning to DFW Airport.

The forecaster-in-charge testified that if, in his judgment, 40-knot winds had been associated with Cell "D," he would have issued the required warning. However, based on what was produced by similar weather echoes in the same area during that afternoon and evening, "we had nothing to suggest that we were going to have winds of that magnitude. I elected, therefore, not to issue a warning." He also testified that an Aviation Weather Warning is not meant for aircraft in flight, but is meant for the airport itself. Its primary purpose is to alert airport personnel that tie-down precautions for airplanes and equipment may be required. The meteorologists in the forecast office did not become aware of a thunderstorm at DFW Airport until they received the DFW Airport's 1805 surface weather observation.

Before the onset of the thunderstorm at the airport, the maximum recorded winds were about 10 knots. The forecaster-in-charge testified that the first indication the forecast office had that the wind gusts exceeded 40 knots was when the contract weather observer at DFW Airport called at 1815 and reported that he had recorded wind gusts to 46 knots.

17/ A report from an individual describing what meteorological event is occurring at his or her observation point. The report could include rainfall intensity, the presence or lack of thunder and/or lightning, the presence or lack of hail and the size of the hail, and significant winds.

18/ Thunderstorm--In general, a local storm invariably produced by a cumulonimbus cloud, and always accompanied by lightning and thunder (Glossary of Meteorology: 1959).

Although the television monitor in the forecast office did not incorporate any geographical mapping capability and the overlays used in the forecast office to fix the geographical location of the weather echoes did not depict the location of the DFW Airport, the forecaster-in-charge testified that his decision not to issue aviation weather warnings was based solely on his assessment of the existing meteorological conditions and not on any uncertainty as to the location of DFW Airport.

1.7.3 The Fort Worth ARTCC's Center Weather Service Unit

The terms and conditions establishing a Center Weather Service Unit (CWSU) are contained in a Memorandum of Agreement among the Department of Transportation, the FAA, the National Oceanic and Atmospheric Association (NOAA), and the NWS as amended July 14, 1981. The agreement states that the NWS will operate CWSUs at selected ARTCCs and that,

> These units will each be comprised of four professional meteorologists operating two shifts per day except during periods of extended annual or sick leave as may be determined by the NWS. Operating hours shall be determined in consonance with the Chief of each ARTCC.

The agreement further states, in part, that the FAA will reimburse the NWS for the total personnel costs, including supporting services, relocation costs, and travel costs actually incurred for work performed under the Agreement. Under the terms of the agreement, the FAA could have chosen and received a higher level of staffing by meteorologists at the CWSU at the Fort Worth ARTCC.

The duties and responsibilities of a CWSU are contained in FAA Order 7210.38A, April 6, 1984. According to paragraph 10 of the order, "the primary function and responsibility of the CWSU is to provide meteorological advice and consultation to center operations personnel and other designated FAA Air Traffic Facilities, terminal and FSS [Flight Service Stations], within the ARTCC area of responsibility." The information provided by the CWSU is to be developed "through analysis and interpretation of available weather data and is provided in the form of briefings and other weather products (forecasts and nowcasts)."

The CWSUs at ARTCCs are staffed by NWS meteorologists. FAA ATC personnel serving in the position of weather coordinators provide assistance to the meteorologist. The order requires that the meteorologist will conduct "weather familiarization training as required by the [ARTCC] facility manager."

FAA Order 7210.38A states that the weather coordinator functions as the interface between the NWS meteorologist and the facility air traffic staff and "is primarily responsible for the inter/intra facility dissemination of SIGMETS, CWA and urgent PIREPS [Pilot Reports], and provides assistance in the collection and dissemination of other significant weather information."

FAA Order 7210.38A also states that the Weather Coordinator position will be manned on all shifts "and all personnel assigned to this function must have received prior training in the associated duties and responsibilities." The order further states that, weather and workload conditions permitting, the weather coordinator may perform other operational and administrative functions; "however, the primary duty remains that of weather coordinator."

An Assistant Manager for Traffic Management at the Fort Worth ARTCC testified that all facility personnel assigned to the weather coordinator position were qualified to assume the position "through an on-the-job [training] system." He testified that a formal training course at the FAA Academy in Oklahoma City, Oklahoma, had been suspended about 4 years earlier for lack of students due to the 1981 strike. The course had been reestablished in April 1985 and he testified that two of his traffic managers were currently attending it.

The assistant manager further testified that the weather coordinators at the Fort Worth ARTCC are trained to provide liaison between the CWSU and the ATC personnel in the ARTCC and the other facilities within the ARTCC's air space. He further testified that the weather coordinators are neither trained nor qualified to make weather interpretations or to observe the Remote Radar Weather Display System (RRWDS) in the CWSU.

At the Fort Worth ARTCC, the weather coordinator is assigned to the Traffic Management Unit which, in turn, is responsible for administering the national and local traffic management programs that regulate traffic flow within the ARTCC's air space. The weather coordinator works under the Traffic Manager-in-Charge, who is responsible for regulating and supervising all traffic in the control room.

Paragraph 20 of FAA Order 7210.38A states, in part, that the "total shift staffing and the operational hours of each CWSU shall be specified by the Meteorologist-in-Charge in consonance with the ARTCC facility manager. Shift staffing shall be based upon available manpower, air traffic volume, and weather considerations." NWS meteorologists staff the Fort Worth ARTCC's CWSU between 0600 and 2200. Except for a possible small overlap between the morning and afternoon shifts, only one meteorologist is on duty during the 1400 to 2200 evening shift. On the day of the accident, the meteorologist on duty had reported for his shift at 1400, and the Traffic Manager-in-Charge was also serving as weather coordinator.

The NWS meteorologist on duty at the time of the accident testified that the RRWDS can dial up direct access to five different weather radar sites around the Fort Worth ARTCC's air traffic area, and at the time of the accident Oklahoma City and Stephenville had been selected. The RRWDS is a digitized color display incorporating about a 2-minute delay in its presentation. The RRWDS presents the precipitation in six different colors, and the DFW Airport is located on the display. The RRWDS does not contain height-measuring capability and cannot measure echo intensity at various altitudes as can be done at NWS weather radar sites. As a result, the meteorologist testified that he could interpret the intensity level of a weather cell on the RRWDS, but he could not determine the severity of the weather inside the cell from the return.

The NWS meteorologist testified that on August 2 he took his supper break at 1725. Since the ARTCC's regulations ban food from the radar room, he had to go to the cafeteria, located down a flight of stairs and about 200 feet from the CWSU position. While he could not monitor the weather radar from the cafeteria, he could be paged if he were needed.

The meteorologist testified that there are no normal scheduled times for meal breaks, that all breaks depend upon the existing weather situation, and that, at 1725, he checked the RRWDS before leaving and there were no weather echoes within 10 nmi of the DFW Airport. Although not required to, he notified the assistant traffic manager of his intentions. He testified that he was not paged while in the cafeteria and returned to the CWSU about 1810.

The meteorologist testified that he did not "necessarily" issue a CWA for thunderstorms within 10 nmi of DFW Airport since not all thunderstorms require one to be issued. He testified that only those storms that produce gust fronts and low level windshears, and that "will have a major impact on [airport] traffic require CWAs to be issued." Paragraph 4.3.3, Attachment 1, FAA Order 7210.38A, states in part that

> the CWA is an unscheduled in-flight flow-control, air traffic, and air crew advisory. It is for the guidance of the ARTCC personnel, air crews in flight, designated FAA facilities, and CWSU meteorologists for use in anticipating and avoiding adverse weather conditions in the en route and terminal environments.

FAA Order 7210.38A further states in part that when "current pilot reports or other weather information sources indicate that an existing or anticipated meteorological phenomenon will adversely affect the safe flow of air traffic within the ARTCC area of responsibility," the CWSU meteorologist "may" issue a CWA. "In this situation the data available must be sufficient, in the judgement of the CWSU meteorologist, to support both the issuance of such an advisory and, if necessary, its continuation."

The CWSU meteorologist testified that he normally did not issue a CWA based solely on the intensity levels portrayed on the RRWDS. He testified that had he seen a VIP level 4 storm in the vicinity of DFW Airport on his radar, he would have tried to ascertain the severity of the cell by soliciting PIREPs and ground truth reports. If he had confirmed that the cell was a thunderstorm, he would have formulated a CWA to be delivered to the weather coordinator for transmission to the tower and Terminal Radar Approach Control (TRACON). He estimated it would take about 5 to 10 minutes between composing the CWA and its delivery to the tower and TRACON.

The CWSU meteorologist testified that if he had seen Cell "D," based on its location and rapidity of growth, he would have issued a CWA. In this instance, he thought he might have sought additional information directly from the TRACON or tower cab.

1.7.4 The Contract Weather Observer

Surface weather observations at DFW Airport are provided by a contract weather service whose observers are certificated by the NWS. The weather station is on the second floor of the Delta Air Lines maintenance hangar on the east side of the airport. The contract weather observer on duty at the time of the accident testified that only 50 percent of the sky, from southeast through north, can be seen from inside the weather station; therefore, he either has to go to the hangar roof or out on the taxiway in front of the hangar to observe the sky from the north through east. After completing the sky condition observation, he has to return to the weather station to take the required instrument readings.

The weather observer transmits surface observations locally to user agencies by electrowriter. The electrowriter reproduces the observer's handwritten weather observations in the offices of all agencies subscribing to this service at the same time they are entered on the electrowriter terminal in the weather office. The weather station also transmits, via the electrowriter, the NWS terminal forcasts and NWS aviation weather warnings received over the teletype.

At 1744, the weather observer testified that he went to the the taxiway to begin his scheduled 1751 observation. He completed his sky observations about 1744, returned to the weather station and took the instrument readings required to complete the observation. At 1751, he transmitted the following observation via the electrowriter:

> 1751 - 6,000 feet scattered, estimated ceiling 21,000 feet broken, visibility 11 miles, temperature 101°F.; dew point 65°F.; wind 120° at 08 knots, altimeter setting 29.92 inches of Hg.; cumulonimbus north-northeast, towering cumulus northeast-south-west-north.

The transmission of the observation was completed at 1752.

The weather observer testified that, while observing the sky conditions for the 1751 observation, he noted a rapidly developing cumulonimbus cloud. After transmitting the 1751 observation, he decided to go back outside to see what was happening to the cloud. He returned to the taxiway and "took a good look at the sky. I noticed a rain shower falling from the CB [cumulonimbus cloud] which was north through northeast of where I was located." While he was looking at the sky, he heard thunder at about 1802. The weather observer estimated that the leading edge of the rain shower was about 3 nmi north of the weather station, but he could not, due to the distance, estimate the intensity of the rainfall. After he heard the thunder, he decided to issue a special surface weather observation, "so once again, I had to note the kind and type of clouds. . . out there, how high they were, the visibility . . . how much, if any, lightning there was, where the rain showers were falling, and so forth." After completing his sky condition observations on the taxiway, the weather observer testified that he ran to the weather station to complete the required instrument readings, and, at 1805, issued the following:

> 1805 - Special, estimated ceiling 6,000 feet broken, 21,000 feet broken, visibility 10 miles, wind 070° at 8 knots, altimeter setting 29.92 inches of Hg., thunderstorm began 1802, north-northeast and overhead moving slowly south, occasional lightning cloud to cloud, rain showers unknown intensity north-northeast, towering cumulus northeast-southeast, west.

The transmission of the observation was completed at 1807.

After transmitting the 1805 special observation, the weather observer returned to the taxiway to observe the weather conditions, and, at 1814, he issued the following:

> 1814 - Special, 400 feet scattered, estimated ceiling 6,000 feet broken, 21,000 feet broken, visibility 11 miles, wind 360° at 37 knots gusting 46 knots, altimeter setting 29.93 inches of Hg., thunderstorm north-northeast and overhead moving slowly south, occasional lightning cloud to cloud, rain showers unknown intensity north-northeast, wind shift 1811.

The transmission was completed at 1816.

The weather observer testified that although not required by reporting procedures, he also called the Fort Worth Forecast Office after he transmitted the 1814 special weather observation to ensure that the forecasters were aware of the change in the wind speed.

1.7.5 Delta Air Lines Meteorological and Dispatch Departments

Delta Air Lines Meteorological and Dispatch Departments are colocated at the Atlanta Hartsfield International Airport, Atlanta, Georgia. The Meteorology Department is staffed by 14 meteorologists and 1 manager. The forecast positions, which are manned 7 days a week, 24 hours a day, include: surface, upper air-wind/temperature updates, and upper air-turbulence.

The meteorologist working the surface position issues three daily terminal forecasts for about 85 stations plus amendments as necessary. He is to brief dispatchers at shift changes and at other times as necessary. He can also provide weather updates via the company's radio to en route flightcrews.

On August 2, 1985, the surface meteorologist on duty between 1430 to 2230 did not provide to either the dispatcher or the flightcrew any information on the weather cell that flight 191 penetrated on its final approach. The meteorologist stated that isolated heavy thunderstorms had developed, as forecasted, northeast of the DFW Airport and were noted on the NWS Radar Summary Charts. He also stated, "At the time of the accident I would have placed these cells still some distance northeast of DFW [Airport]. I was surprised when it became obvious the accident was thunderstorm related."

Federal Aviation Regulation 14 CFR 121.601(c) requires, in part, that dispatchers provide the pilot-in-command during a flight with "any additional information of meteorological conditions . . . that may affect the safety of the flight." This information includes "adverse weather phenomena such as . . . thunderstorms and low altitude wind shear."

The Delta dispatcher on duty at the time of the accident testified that, at 1745 and 1750, he had tried to call up the Stephenville radar site on his television monitor, but the line was busy both times and he did not try again. The dispatcher did not contact flight 191 at any time after the flight had checked in over New Orleans with its required progress report.

1.7.6 Witness Statements

Ground Witnesses.--Witnesses were in agreement that the storm was located north of DFW Airport at or just before the accident. The southern edge of the storm was just north of State Highway 114 or about 1.5 to 2 miles north of the approach end of runway 17L. The eastern and western edges of the storm were 2 miles east and 1 mile west of the extended centerline of runway 17L.

Witnesses said that the storm was moving southward slowly. Eight witnesses on the highway said that the precipitation from the storm had reached or was just reaching the highway as flight 191 went across it. Those witnesses who had encountered rain that evening described the rainfall as heavy to intense. Witnesses on the highway who saw flight 191 emerge from the rain described it as coming out of a wall or curtain of water.

Fifteen witnesses reported seeing lightning and some witnesses heard thunder, and both were reported to have occurred when the storm was near the airport.

Witnesses who commented on the wind indicated that the wind flow was outward from the storm. One witness reported that several highway traffic signs had been uprooted and blown over. Another witness, about 3 to 4 miles north of the airport, reported that a trailer containing 1,200 pounds of fertilizer was overturned during the passage of the storm.

Another witness, about 4 miles north-northwest of DFW Airport, said he saw a large thunderstorm building just north of the airport. He saw two rain shafts coming from the cloud. The storm was divided into two main areas, and the most intense area was just north of runways 17L and 17R. The intense area produced multiple cloud-to-cloud and cloud-to-ground lightning bolts. About 1755, the witness said that he saw what appeared to be a small funnel cloud hanging out of the storm. The funnel was short, very tight, and had "the appearance of a water spout." The base was very high, about at "the eight thousand foot level," and it was hanging out of the west side of the cloud. According to the witness, the storm began to dissipate about 3 minutes later and the wind suddenly increased to about 50 mph or greater.

Passengers on Flight 191.--The surviving passengers were seated in rows 21 through 46. Survivors, passengers and cabin crew who were interviewed, stated that the airplane entered heavy rain during the descent. Some described the color of the clouds outside the airplane as blue-black or said that it got dark outside the airplane. All of them stated that the airplane encountered turbulence before the impact and one, a flight attendant, said the approach was "really bumpy." The other flight attendant stated that it got "very rough" during the approach, and "we were moving in a lateral direction, being tossed about, up and down, left and right."

Flightcrews Landing at or Departing DFW Airport.--Flight 191 was third to land behind flight 351 (a Boeing 727) and a Learjet 25; American flight 539 (a McDonnell Douglas MD-80) was to land behind flight 191.

The captain of flight 351 testified that he had been directed to execute a missed approach because the airplane landing ahead of him had not been able to clear the runway in time. During his approach to the DFW Airport, the captain said he saw only scattered clouds and one "thunderstorm northeast of the field." He said that his Bendix monochromatic weather radar was set in contour mode and the cell did not contour. He could see the cell from the cockpit and "it looked harmless . . . like showers." The captain testified that after passing the outer marker inbound he did not encounter any rain or turbulence, and he did not see any lightning. After the missed approach, flight 351 was vectored to the downwind leg for runway 17L and sequenced into the traffic flow for another approach. After turning on base leg at 2,500 feet, the flight encountered a windshear and lost about 20 KIAS traversing the area of the shear.

PIREP criteria are contained in the General Operating and Flight Rules (14 CFR 91) and the Certification and Operations: Domestic, Flag, and Supplemental Air Carrier and Commercial Operators of Large Aircraft (14 CFR Part 121) sections of the Federal Aviation Regulations. Title 14 CFR 91.125 requires the pilot in command of an airplane operated under IFR to maintain a "continuous watch . . . on the appropriate frequency and shall report by radio as soon as possible . . . (b) Any unforecast weather conditions encountered; and (c) Any other information relating to safety of flight."

Title 14 CFR 121.561 states as follows:

> (a) Whenever he encounters a meteorological condition or an irregularity in a ground or navigational facility, in flight, the knowledge of which he considers essential to the safety of other flights, the pilot in command shall notify an appropriate ground station as soon as practicable.

(b) The ground radio station that is notified under paragraph (a) of this section shall report this information to the agency directly responsible for operating the facility.

The captain of flight 351 testified that he was familiar with the provisions of 14 CFR 121.561, but he did not report the encounter because he believed that "a windshear of 20 knots at 2,500 feet at [the] airspeed I was at is negligible and certainly would not interfere with the safety of anyone's flight."

Flight 351 was cleared for its second approach to runway 17L at 1800:38 and landed about 1804. The captain testified that he did not go through any weather cells and that, while on final, the nearest one was about 2 miles east of his aircraft. The captain said that, after departing the outer marker inbound he encountered heavy rain which lasted until he descended through 1,000 feet. He did not encounter any turbulence or windshear, and he did not see any lightning during the approach.

The captain also testified that the airplane's weather radar was not dependable when "you're close to a buildup or thunderstorm." He said that there was not enough definition and that he believed that you would have to be about "ten miles" from the storm to really look at it well.

The Learjet preceding flight 191 in the landing sequence had a Primus model 400 color weather radar. The pilot stated that he used the radar until he was about 25 nmi from DFW Airport and that "nothing looked bad." He was able to see the cells visually. At the public hearing, he testified that he saw this "little buildup" as he approached the airport, and that "it looked harmless." Although his weather radar was still on, he did not recall looking at his radar as he turned on the final approach course.

About 1803, as the Learjet approached the outer marker, the pilot retarded power to decelerate the airplane from 170 to 153 KIAS, the maximum flap extension speed. At 153 KIAS, with power still retarded, he extended the landing gear and flaps and placed the airplane into its landing configuration. While the flaps and landing gear were extending, the airspeed dropped from 153 to 125 KIAS. Since the airplane's power had been reduced "considerably" to slow it from 170 KIAS, and since he had not added power while the flaps and landing gear were in transit, the pilot testified that he did not perceive the deceleration from 153 to 125 KIAS to be the result of a windshear encounter.

The pilot testified that since he had encountered "light to moderate turbulence" after passing the outer marker, he decided to maintain 150 KIAS on the approach instead of the computed 125 KIAS approach speed. After passing the marker, the airplane entered heavy rain and he lost all forward visibility. Since he had no forward visibility, he thought that if the airplane did not get out of the rain, he might not be able to land, so he decided to "stay high" and fly above the glideslope.

The pilot testified that when he emerged from the rain and saw the runway, the airplane was "high and hot" and they landed "long" because of the approach. After the Learjet landed, the local controller asked the pilot to clear the runway at the high-speed turnoff; however, because the airplane was going too fast and was passing the turnoff, he could not accommodate the local controller. The controller then asked him to "Expedite down to the [next taxiway]." He said that he cleared the runway at the next taxiway and after clearing the runway he looked north and saw the smoke coming from the Delta crash site. With regard to reporting the weather to the tower, the captain testified that he had nothing to report, "the only thing that we encountered was the heavy rain."

Flight 539 was the next airplane behind flight 191 in the landing sequence. Flight 539 was equipped with a Bendix model RDR-4A color radar which, in the opinion of the captain, was "generally a very effective radar."

The captain testified that flight 539 was about 5 to 6 nmi behind flight 191 when flight 539 turned on the final approach course. He testified that there was a buildup in front of flight 539 and almost directly over the final approach course with heavy showers falling from the buildup's base. The captain testified that he observed the buildup on his radar at or inside the outer marker. The buildup was portrayed in red, and no lead-in green and yellow colors were displayed. (The color radar displays a storm in three colors--green, yellow, and red--on a black screen. Green indicates areas of light to moderate rainfall, yellow indicates areas of heavy rainfall, and red indicates areas of heavy and greater rainfall rates or a precipitation reflectivity level in excess of 40 dBZ. The black screen around the perimeter of the cell indicates areas of no detectable rates of rainfall.)

The captain said that they maintained visual contact with flight 191 until it entered the rain shower beneath the buildup. He estimated that flight 191 was about 800 feet AGL when it entered the rain, and he also saw lightning in the area where he lost sight of flight 191. His first officer stated that a cell "with abundant lightning" was directly off the approach end of runway 17L and he saw flight 191 "penetrate the cell."

Although the captain of flight 539 testified that, based on what he had observed visually and on his radar, he was considering rejecting the approach, he continued inbound on the approach until, at 1806:21, the local controller requested flight 539 to "go around." The captain testified that, on receipt of the request, the first officer, who was flying the airplane, added power, leveled off, and turned right to try to go around the right edge of the buildup. "We took it [the airplane] . . . through the fringe area of the buildup, and were in it for approximately ten seconds or so, and then broke out on the other side." While the airplane was in the fringe area, the captain testified, "we were in moderate to heavy rain, and . . . it lasted for most of the time we were in the cloud."

About the time of the accident, Delta flight 1067 was inbound to DFW Airport from the east with its captain observing the airport weather on its Bendix RDR-4A color weather radar. The captain said that when the airplane was about 140 nmi east of DFW Airport and with the 160 nmi range selected on the radar, he saw some "green specks" displayed on a north-south line over the Dallas/Fort Worth VORTAC located about 1 nmi south of the southern end of runway 17L. As the airplane approached the Blue Ridge VORTAC, the captain decreased the radar's range setting to 80 nmi and the "green specks had become yellow cells with a small amount of red contour."

After leaving Blue Ridge VORTAC, the captain said he decreased the radar's range setting to 40 nmi and the cells "had become mostly red with only a trace of yellow around the fringes." (According to ATC data, at 1805, flight 1067 was 8 nmi southwest of the Blue Ridge VORTAC.)

After leaving Baton intersection (27 nmi northeast of DFW Airport) and while descending from 9,000 feet toward the airport, the captain said that, "the cell over the airport was a solid red contour with no yellow or green around the edges and was 15 nmi in diameter . . . . The other cells in the short north-south line were much smaller than the one over the field, and I considered them to be insignificant." The captain compared the rate of development of the cell to "an atomic bomb explosion filmed in slow motion."

Shortly after leaving Baton intersection, the captain was told by ATC that DFW Airport was closed because of the accident. The captain stated that "due to traffic considerations, I was very close to the cell before I could turn . . . and divert to Oklahoma City. I was able to view the cell . . . on 20 nmi radar range. The cell was solid contour and still building." (Transitional areas or rainfall gradients on the radar display are the distances between the leading edges of each of the colors displayed within the portrayed cell or weather echo. Turbulence usually occurs near cells with cores exceeding 40 dBZ. A narrow transitional area or steep rainfall gradient can indicate the presence of *moderate or greater turbulence.*)

Pilots on the Ground.--Because of the convective weather impacting the ATC route structure, the Severe Weather Avoidance Plan (SWAP) flow control procedures were in effect and were delaying departures from DFW Airport. Many airplanes were positioned on the ramp accessing runway 17L (see appendix D) and along the taxiways leading to the runway awaiting takeoff clearance. Flightcrews in these airplanes as well as on other airplanes located elsewhere at the airport saw the storm approach.

All crewmembers who saw the storm either at or just before the accident stated that it was north-northeast of the airport with its southern or leading edge about 1 to 5 miles from their positions. All of these personnel saw heavy rain falling from the cell and some described the rainfall as a "curtain" of either rain or water. The first officer of a DC-10 holding just west of the threshold of runway 17L stated that he saw an "opaque curtain of rain illuminated by frequent lightning flashes" before the accident. The first officer also noted that at this time the wind sock adjacent to his airplane's position showed the direction of the wind was from 080°. With regard to lightning, crewmembers on two other airplanes said that they saw lightning in the area of the storm cell before the accident.

The crewmembers observing the storm reported that it was moving toward the airport but that it did not reach their position until after flight 191 had crashed. The estimates of the time interval between the crash and the arrival of the storm at their airplanes varied from 1 or 2 minutes to as long as from 10 or 15 minutes. The last estimate was from a crewmember whose airplane was on the outer taxiway at cross taxiway 21 East (21E).

Two captains reported seeing funnel structures within the rainfall area. The captain of a Boeing 727 holding just short of the threshold of runway 17L testified that his airplane was facing east and that he saw a "rain shower approaching the field from the north." When the shower was about 1 to 3 miles north of his airplane, he stated that he saw a funnel-shaped structure within the rain extending from the base of the cloud to the ground. He compared the structure to a water spout he had seen "off the coast of Florida." He testified that he saw "one or two lightning strikes, cloud to ground" before he saw the funnel and that the lightning was "kind of to the right of where we saw the tornado."

The Boeing 727 was equipped with a Bendix model RDR-1E monochromatic weather radar. The radar was on, the 80-nmi range was selected, and the antenna had been tilted up to eliminate ground clutter. The captain testified that the shower "was directly to our left, about 90° to us, so we didn't pick up anything there." (The azimuth limits of the radar antenna are 90° either side of the longitudinal centerline of the fuselage of the airplane.)

The captain testified that after trying to locate the shower on his radar, he looked up and saw flight 191 crash and that the rain from the storm reached his airplane shortly thereafter. He testified that his radio was tuned to the tower's local control frequency, that he had "counted 20 aircraft on the outer taxiway," and that airplanes were taking off "one right after the other, so there was quite a bit of congestion on the frequency." He testified that he would not have hesitated to break in and report the hazardous weather he had seen, but he saw flight 191 crash before he was able to assimilate what he had seen and that after seeing the accident, "I no longer had any thought of reporting the tornado."

The other captain who observed a funnel structure had just completed an ILS approach to runway 17L. He crossed the outer marker, 5.1 nmi from the end of runway 17L, at 1800:38; testified that he saw two lightning strikes, one on each side of the airplane, after passing the outer marker. After landing, the captain turned his Boeing 737 off the runway onto taxiway 29, and was instructed by the local controller east to hold short of runway 17R. A transcript of the airplane's CVR showed that, at 1803:32, the first officer asked, "Is that a waterspout out there?" The captain testified that he looked out the first officer's side window, and "for about, . . . two or three seconds, . . . it did look, in fact, [like] a tornado out there. It was essentially two very distinct sheets . . . of water . . . . There was a tubular area between the sheets that I think, in retrospect, was the background sky color, which led me to believe it was a tornado."

At 1804:44, after viewing the funnel-like structure, the captain was cleared to taxi across runway 17R. He testified that he had to divert his attention from the weather to taxi his airplane and he did not inform the local controller of what he had just seen. He also did not report that he had seen lightning on the final approach. He testified that he planned to report what he had seen to the ground controller as soon as he reached the parking ramp and was cleared to transfer to ground control's radio frequency. However, he did not make the report.

The flightcrew of one Boeing 737 did use its weather radar to examine the storm shortly before the accident. The airplane had its Bendix model RDR-4A color weather radar on and was facing north on the outer taxiway at the intersection with cross taxiway 21B. After seeing the storm, the first officer selected the 20-nmi range setting, and used full antenna tilt--from 0° to +15°--to examine the storm. The captain said that the storm cell, based on an earlier visual observation, was the easternmost cell in a "short line" of two to four medium-sized cells oriented along an east-west line. When viewed on the airplane's radar the storm cell was about 4 miles from their position. He said the cell was "3 to 5 miles thick and about 4 miles long." The first officer said that the southern edge of the cell was about 5 miles from their position. "The size of the cell was about that of a silver dollar on the radar screen, the intensity was depicted by complete red, [and] there were no transitional colors at the edge of the cell, just solid red."

1.8 Navigational Aids

Not applicable.

1.9 Communications

There were no known communication difficulties.

1.10 Aerodrome Information

DFW Airport, elevation 603 feet, is located 13 miles northwest of Dallas, Texas, and is served by five runways: 18R/36L, 18L/36R, 13L/31R, 17R/35L, and 17L/35R.

(See appendix D.) The runways are served by seven ILS and nondirectional beacon (NDB) instrument approaches.

Runway 17L is 11,388 feet long and 150 feet wide and has a grooved concrete surface. The runway has an approach lighting system with sequenced flashers, runway edge lighting, and centerline lighting, and is served by an ILS instrument approach.

The ILS approach to runway 17L transmits on 109.1 megahertz (Mhz). The localizer course is 173°. The touchdown zone (TDZ) elevation is 562 feet and the minimums for the approach are 200 feet AGL and 1/2 mile visibility. The final approach fix (FAF), Jiffy, has a low-frequency radio compass locator and outer marker radio transmitter (LOM) and is located 5.1 nmi from the runway threshold. The minimum altitude at Jiffy and the decision height (DH) for the approach are 2,300 feet and 762 feet, respectively. (See appendix E.)

On August 2, 1985, shortly after the accident, ILS runway 17L was flight-checked, and the facility operation was found to be satisfactory.

1.10.1 Low Level Wind Shear Alert System

The Low Level Wind Shear Alert System (LLWAS) at the DFW Airport was operational at the time of the accident. The system, which has no recording capability, consists of six 20-foot-high vector-vane type of sensors located strategically throughout the airport property. The northeast, southeast, southwest, west, and northwest sensors are located on the airport perimeter; the centerfield sensor is located about 4,463 feet south of the thresholds of runways 17L and 17R and midway between the two runways. The northeast and northwest sensors were nearest to the storm and are located about 3,000 feet north of the thresholds of runways 17 left and right and 18 left and right, respectively.

The six sensors provide wind direction and speed data to a computer and six display units; two display units are located on the east and west sides of the tower cab and four are in the TRACON. The TRACON units display only centerfield sensor data and are located at the following radar control positions: feeder east low, departure south, arrival 1, and arrival 2.

The top row of windows of the tower cab's display units show the centerfield wind direction, speed, and gust speed. The next five rows display wind information from the five peripheral sensors. When a peripheral sensor's average wind reading for 30 seconds shows a vector difference (direction and speed) of 15 knots or more from that of the centerfield sensor's wind reading, an aural alarm sounds and the digital information from the affected sensor or sensors starts flashing in the appropriate row or rows of the tower displays. The flashing continues for five scans of the system's computer, or about 37.5 seconds; the aural alarm lasts for two scans or 15 seconds. The gust velocity is shown in its appropriate window anytime the instantaneous wind speed retrieved from the centerfield sensor exceeds by more than 9 knots the average wind speed retrieved over the previous 2 minutes. Wind gust information is not shown on the readouts for the peripheral sensors. The digital readouts for the peripheral sensors will not appear in the tower displays unless an alert has occurred. However, a controller can obtain a readout for any of the five peripheral sensors by pressing the appropriate blanking switch on the display unit. The readout will be retained until the controller presses the blanking switch.

The LLWAS has several limitations: winds above the sensors are not detected; winds beyond the peripheral sensors are not detected; updrafts and downdrafts are not detected; and if a shear boundary happens to pass a particular peripheral sensor and the centerfield sensor simultaneously, an alarm will not occur. In addition, the dimensions of some meteorological phenomena--microbursts or macrobursts--may be smaller than the spacing between the sensors and thus may not be detected. However, since the downward flow in macrobursts and microbursts turns horizontally as it approaches the ground, an outward flowing shear boundary is established which eventually affects one of the sensors and places the system in alert. The controllers in the DFW Airport tower cab stated that the LLWAS went into alert either about the time the storm reached the north end of the airport or about 10 to 12 minutes after the accident, and when they checked the display, all sensors were in alarm.

Following the accident, the LLWAS was inspected by FAA maintenance personnel and, on August 3, 1985, the system was recertified. The recertification included all system components except the sensor components which measure wind speed and direction. This equipment was not recertified because the equipment required to calibrate the anemometer portion of the sensor was not available at the DFW Airport. On August 12, 1985, the required equipment was brought to DFW Airport. All six LLWAS sensors were removed one at a time, their wind speed and direction measuring components were checked, recalibrated if required, and then replaced at their designated sites. The five perimeter sensors were found to have been accurate. Although the centerfield sensor's wind direction measuring components were found to have been accurate, the wind speed measuring components were reading 4 knots below the speed of the inserted check wind. The centerfield sensor's vector-vane was removed and replaced and the sensor was returned to service.

The cup type of wind sensor used by the contract weather observer at the airport is located within 30 to 40 feet of the LLWAS centerfield vector-vane type of sensor. The weather observer's sensor records wind speed but not direction, and the recorder graph showed that the winds were below 10 knots until 1750. From 1750 until about 1811, the winds averaged between 10 and 12 knots. Between about 1811 and 1815, the winds increased to 46 knots. Between 1750 and 1811, the wind direction, as reported by the TRACON controllers and the local controller, varied between 60° and 90°.

1.11 Flight Recorders

The airplane was equipped with a Fairchild model A-100 Cockpit Voice Recorder (CVR), serial No. 2911, and a Lockheed Air Service Model 209E Digital Flight Data Recorder (DFDR), serial No 586. The CVR and DFDR were removed from the airplane wreckage and taken to the Safety Board's Washington, D.C., Laboratory where they were examined and read out.

The CVR was undamaged. The tape was removed and copied, a time correlation was made with ATC transmissions, and a transcript containing the last 30 minutes of the flight was prepared (see appendix F). The transcript was complicated because the flightcrew was using the cockpit speakers, and cockpit conversation was partially obliterated by incoming transmissions from ATC and other airplanes. Several transmissions from ATC and other airplanes were not transcribed, but are available in the ATC transcripts.

The DFDR was undamaged and in working order on arrival at the Safety Board's laboratory, and its tape was removed and read out. The examination of the readout disclosed two periods where data were lost due to loss of synchronization (sync loss). The first sync loss occurred 9 seconds before the end of the recording and lasted less than 1 second. The second sync loss occurred 3.45 seconds later and covered a

4-second period where sync was intermittent. Sync was regained for the final 2 seconds of the recorded data. Some of these lost data were retrieved through the use of recovery techniques.

The DFDR tape contained, among other monitored parameters, the following data: indicated airspeed; heading; pitch and roll attitudes; angle of attack; position of the lift and drag devices; pitch, roll, and yaw control inputs; rudder, aileron, elevator, and stabilizer trim positions; vertical and longitudinal acceleration forces (Gs); and VHF radio keying.

The VHF radio keying data were correlated to the times contained on the ATC transcript for communications between flight 191 and the ATC facilities. The times were correlated to establish a real-time reference for the various events contained on the DFDR digital readout. The real-time correlation was used to prepare a graphic display of flight 191's landing approach to runway 17L containing the following selected parameters: indicated airspeed; magnetic heading; m.s.l. altitude; engine pressure ratios (EPR) 19/; control column and control wheel positions; pitch and roll attitude; angle of attack; vertical Gs; and selected CVR comments (see appendix I).

1.12 Wreckage and Impact Information

The airplane touched down initially in a plowed field about 360 feet east of the extended centerline of runway 17L and 6,336 feet north of the runway threshold in a wings-level nose-high attitude and on a heading of about 167° magnetic. The left and right main gear tracks extended about 240 feet beyond the initial touchdown point, and the depth of the left and right main gear tracks was 6 to 8 inches and 5 to 6 inches, respectively. The main gear tracks then disappeared for about 320 feet, reappeared for a short distance, and finally touched down just before the north edge of State Highway 114. The nose gear touched down in the westbound lane of the highway.

The airplane knocked over a highway light standard on the north side of the highway and collided with a westbound automobile about 1,500 feet beyond the initial touchdown point. The automobile, which was destroyed, contained a small section of No. 1 engine inlet cowling, and metal pieces from the automobile were found in the No. 1 engine compressor inlet. Measurement of the distance between the main landing gear tracks showed that the airplane was yawed significantly to the left when it crossed the highway. The first pieces from the airplane--pieces of tire tread--were found just beyond the eastbound lanes of the highway, and two light standards on the southern edge of the westbound lanes were knocked over. The airplane breakup, which began as it traversed the highway, continued as it proceeded along the ground toward the two water tanks located on the airport about 1,700 feet beyond the highway.

A 45-foot by 12-foot crater was located about 700 feet beyond the highway. The 2.5-foot-deep crater contained pieces from the accessory gearbox of the No. 1 engine, and the No. 1 engine came to rest about 845 feet beyond the crater. Other components located along the track between the highway and the water tanks included, among others, portions of the nose landing gear, the left horizontal stabilizer, engine components, and pieces of the wing trailing edge flaps and the leading edge slats.

19/ Engine Pressure Ratio (EPR) is the turbine discharge total pressure divided by total pressure at the compressor inlet; the higher the EPR, the greater the engine thrust output.

The airplane grazed the north water tank and then impacted the south water tank--about 3,195 feet beyond initial touchdown--and broke apart. The fuselage, from the nose aft to fuselage station 1365 (FS 1365), was destroyed. Both wing sections outboard of the engine pylons separated during the breakup. The left wing came to rest in two inverted sections about 1,125 feet south of the south water tank. The wing sections and attached sections of the trailing edge flaps and leading edge slats were burned extensively. The outboard section of the right wing came to rest in an inverted position about 775 feet south of the south water tank. The No. 3 engine pylon was attached to the wing and the No. 3 engine was partially attached to the pylon. Both wings left a trail of wing components and burning fuel between the water tank and their final positions.

Portions of the airplane were scattered throughout the area extending from the two water tanks to about 1,200 feet south of the southernmost tank. Examination of the wreckage showed that all of the recovered structural components in the area adjacent to and south of the water tanks were sooted and damaged to varying degrees by postimpact fire and heat. Examination of the wreckage did not disclose any evidence of preimpact separation or failure.

The investigation team found the aft fuselage section containing the rear cabin and the empennage was in an upright position. Passengers and flight attendants reported that this section came to rest on its left side and was rolled to the upright position by wind gusts after the arrival of the rescue personnel. The section was relatively intact and included the No. 2 engine and associated ducting, the right stabilizer and elevator, and the base of the vertical stabilizer and rudder. The upper 12 feet of the vertical stabilizer and rudder had separated as a unit during the impact sequence and was found about 100 feet north of the aft fuselage section.

Examination of the recovered sections of the trailing edge flaps and leading edge slats showed that the flaps were extended to 33° and that all leading edge slats were extended.

The airplane wreckage was examined for evidence of an in-flight lightning strike. Although the disintegration of the airplane after it struck the southern water tank limited the amount of structure available for inspection, 33 separate structural segments ranging from the nose landing gear strut to the empennage were located, identified, and examined. The examination, which included all accessible control surfaces, leading edge slats, and trailing edge flaps, and static discharge wicks, found no evidence to indicate that the airplane had been struck by lightning during the landing approach.

The airplane was damaged so severely by impact and postcrash fire and heat that little meaningful information was obtained by examination of its systems and cockpit.

Powerplants.--The No. 1 engine separated from the airplane south of State Highway 114. Ground scars indicate that the engine tumbled and rolled about 800 feet along the ground before coming to a stop. During the tumbling and rolling, the engine was damaged extensively and shed most attached accessories, the engine reverser components, and other engine components. Examination of the engine's rotating components and various components of the thrust reverser system indicated that, at the time of separation, the engine was capable of producing power and was in the full reverse thrust position. The manufacturer's specifications state that, during landing, the reversers will deploy in 1.95 seconds; 2.1 seconds are required to move the reversers from the deployed position to the stowed position.

The No. 2 engine remained in position in the aft section of the fuselage, but its left side was damaged significantly by impact forces. The engine inlet and fan section, which had been protected by the fuselage structure during the crash, exhibited minor damage from the ingestion of miscellaneous debris, such as airplane seat cushions, seat sections, and other pieces of the airplane's interior furnishings. This debris was found as far back as the high-pressure compressor. Examination of the engine's rotating and thrust reverser components indicated that the engine was capable of producing power at impact and that it was in the full reverse thrust position, but that it had been commanded to the stow or forward thrust position.

The No. 3 engine, which had remained with the right wing during the airplane breakup, was found with its inlet section pointing opposite to the direction of flight. The engine was damaged severely during the impact sequence. Examination of the rotating components of the engine indicated that it was developing power at impact. Examination of the components of the thrust reverser system indicated that the system had been commanded to the stow or forward thrust position, and the thrust-reversing components in the engine were in transit at impact.

1.13 Medical and Pathological Information

The three flightcrew members sustained fatal injuries as a result of the accident. The pathological examinations disclosed no abnormal conditions. Toxicological analysis of the flightcrew was limited by the availability of suitable specimens and the following results were the only ones possible to obtain. These results were reported by the FAA's Civil Aeromedical Institute (CAMI): Ethyl alcohol was not detected in either the captain or first officer. Carbon monoxide was not detected in the first officer.

1.14 Fire

Passengers saw fire enter the left side of the mid-cabin area after the airplane struck the automobile and before its left side struck the water tanks. The right exterior surface of the separated rear cabin section containing the majority of the survivors was sooted heavily, but the interior of the cabin was not damaged by heat. Parts of the airplane forward of the separated rear cabin section were subjected to severe postimpact and ground fire.

1.15 Survival Aspects

The airplane's passenger cabin contained 46 rows of seats and a total of 302 seats. (See figure 3.) There were 152 passengers on board flight 191: 71 adult males; 62 adult females; 18 children (24 months or older, but younger than 16 years); and one infant (younger than 24 months). The ages of the passengers ranged from 20 months to 70 years. In addition, 11 crewmembers were aboard.

The fuselage forward of FS 1365--forward of seat row 34--including the cockpit disintegrated after the airplane struck the water tanks. However, the passengers said fire entered the cabin through the mid-cabin left wall before the airplane struck the water tanks, and they tried to shield themselves from the flames as the fire propagated into the cabin. The forward cabin containing the cockpit and first 12 rows of passenger seats was destroyed on impact with the water tanks, and there were no survivors from this part of the airplane.

The mid-cabin section was also destroyed. Some of passengers seated in this section, some still in their seats, were ejected onto the ground. Of the 60 passengers seated in this section, 52 were killed. All 8 survivors suffered blunt force trauma; 7 of the 8 survivors sustained thermal injuries in addition to blunt force trauma. One of these 8 passengers had been seated in row 21, the remaining 7 were seated between rows 27 and 33.

The rear fuselage separated from the airplane between seat rows 33 and 34 and the separated rear cabin section contained 33 passengers and 4 flight attendants. Of these 37 persons, 17, including 1 flight attendant, died. Of the 20 survivors, 18 received injuries ranging from serious to minor, and 2 received no injuries. None of these survivors sustained thermal injuries.

There was massive disruption of cabin floor, walls, and ceiling of the separated rear cabin section beginning at the point of separation and extending rearward to just forward of row 40. Fifteen persons, including 2 flight attendants, were seated in this part of the cabin: 10 passengers and 1 flight attendant were killed, 3 passengers were injured seriously, and 1 flight attendant had minor injuries.

Except for the left cabin wall, which was missing, the remainder of the separated rear cabin section from row 40 aft to row 46 was relatively undamaged. Six passengers seated along the missing left cabin wall were killed. The remaining 16 occupants of this cabin section, including 2 flight attendants, sustained serious and minor injuries, and 2 passengers were not injured.

The rear cabin section came to rest on its left side. The survivors were either flung from the airplane in their seats or released themselves from their seats and exited at the forward end of the separated fuselage section or through the missing left wall. One flight attendant and three passengers could not escape from the cabin because of injuries and were removed by fellow passengers and rescue personnel. Two other flight attendants had only minor injuries and were able to escape unaided after shouting commands to the passengers to get out of the cabin. The flight attendant seated at the right rear (R-4) exit had difficulty releasing her seatbelt because the buckle was located on her left hip and her weight was on the buckle. The passengers and flight attendants were covered with fuel and some had fuel on their hands and in their eyes, which caused difficulties in climbing down the cabin to the hole created by the missing left cabin wall. Some persons were able to climb downward to the hole over seats while others fell the width of the cabin to the ground.

Shortly after most of the passengers and flight attendants had exited, high winds blew the rear cabin upright and rescue personnel removed two passengers.

1.15.1 Emergency Response

Three fire stations are located on DFW Airport. Fire station No. 1 was about 2 miles south of the accident site; station No. 2 was about 3 miles west of the site; and station No. 3 was about 0.5 mile southeast of the site. At 1806, the DFW Airport's Department of Public Safety (DPS) Communications Center in the airport's Fire Station No. 1 was notified of the accident and its location. The communications center immediately alerted all fire and emergency units. Fire trucks responded from the three airport fire stations, and additional firefighting and police personnel responded from various locations around DFW Airport.

Within 45 seconds after notification, three airport fire trucks from fire station No. 3 were at the accident scene, three more fire trucks from fire station No. 1 arrived within 4 minutes, and two more from fire station No. 2 arrived within 5 minutes after notification. The fire trucks had 15,100 gallons of water, 1,695 gallons of aqueous film-forming foam, and 3,000 pounds of dry chemical agents. Twenty-six DPS personnel, including 16 Emergency Medical Technicians (EMT) and 2 paramedics, were also at the scene. Despite heavy rains, high winds, and wind gusts from varying directions which hampered the application of fire extinguishants, most of the fires were either put out or under control within about 10 minutes after notification. As fires came under control, the firefighters assisted in rescuing trapped and injured persons.

The airport's DPS Mobile Intensive Care Unit and Medical Patrol Vehicles arrived at the scene about 4 minutes after notification, or about 1810. Triage stations were established and triage procedures were implemented. Typical aid given to victims at the site was treatment for shock, dressing of traumatic injuries including burns, and many actions to stop profuse bleeding. The EMTs estimated that without the on-scene triage procedures and treatment, at least 50 percent of the surviving passengers would have died.

At 1814, the DPS Communications Center operator, using a mutual aid agency notification checklist, began to notify off-airport police, fire, and ambulance agencies to request assistance as prescribed in the FAA-approved DFW Airport Emergency Plan. The checklist required the operator to make 21 telephone calls (many with alternate numbers), 2 radio notifications, and 2 off-airport alert broadcasts, while simultaneously monitoring the airport's primary police radio channel. The operator did not complete the checklist until 45 minutes after the accident.

Parkland Hospital in Dallas, about 12 miles from the airport, was advised initially of the accident at 1819 by the airport's paramedic unit and at 1831 by the DPS operator. By the time the trauma team from Parkland Hospital arrived, about 35 to 40 minutes after the accident, the majority of the injured had been transported to nearby hospitals.

At 1828, the DPS operator notified the John Peter Smith Hospital in Fort Worth; however, the Hurst-Euless-Bedford and Northeast Community Hospitals, which are closer to DFW Airport, were not notified although both received injured persons from the crash. None of the hospitals received notification on victim status or intended destinations.

The adjacent communities of Irving, Grapevine, and Hurst did not receive specific requests for ambulances; however, the ambulance company in Hurst overhead the DFW Airport's radio crash alert and responded quickly after confirming the accident with the airport by telephone. Ambulances were not requested from Grapevine until after the Grapevine fire chief met with the airport's fire chief at the accident site at 1840. The city of Irving did not receive a request for ambulances although the fire chief did dispatch an Emergency Medical Service (EMS) unit to the airport to ask if ambulance assistance was needed.

Although the DFW Airport Emergency Plan contained procedures for requesting mutual aid ambulances, off-airport agencies did not clearly understand what assistance was being requested. In some cases, only fire units were dispatched when ambulances were also expected.

The DFW Airport Emergency Plan met the requirements of 14 CFR 139.55. The last FAA certification inspection of the airport and the emergency plan was completed November 14-15, 1984, and the last disaster drill was conducted by the airport in May 1979.

1.16 Tests and Research

1.16.1 Windshear Research

Windshear has long been identified as a flight hazard and one that can be extremely dangerous during takeoff and landing operations. According to FAA Advisory Circular (AC) 00-50A, "Wind shear is best described as a change in wind direction and/or speed in a very short distance in the atmosphere. Under certain conditions, the atmosphere is capable of producing some dramatic shears very close to the ground. . . ." One of the atmospheric conditions capable of producing "dramatic shears" is the downburst from convective or cumuliform clouds. (See appendix G.)

A downburst 20/ is a strong downdraft which induces an outburst of highly divergent damaging winds on or near the ground. Downbursts vary from less than 1 kilometer (0.62 mile) to tens of kilometers in diameter. Downbursts are subdivided into macrobursts and microbursts according to their horizontal scale of damaging winds. A macroburst's horizontal wind field extends in excess of 4 kilometers (2.5 miles) in diameter, whereas the microburst's horizontal wind field extends less than 4 kilometers (2.5 miles) in diameter. (See figure 4.)

The hazards to flight inherent in downbursts were demonstrated on July 9, 1982, at Kenner, Louisiana, when a Pan American World Airways Boeing 727 crashed after encountering a microburst shortly after takeoff. One hundred and forty-five passengers and 8 persons on the ground were killed in the accident. The Safety Board determined that the probable cause of the accident

> was the airplane's encounter during the liftoff and initial climb phase of flight with a microburst-induced windshear which imposed a downdraft and decreasing headwind, the effects of which the pilot would have had difficulty recognizing and reacting to in time for the airplane's descent to be arrested before its impact with trees. 21/

Much of the recent investigation of the downburst phenomenon has been concentrated geographically around Stapleton International Airport, Denver, Colorado, during two research projects: the Joint Airport Weather Study (JAWS), which ended August 13, 1982, and the Classify, Locate, and Avoid Wind Shear (CLAWS) Project which began July 2, 1984, and ended August 15, 1984.

The director of the JAWS and CLAWS programs testified that the distance across a microbust can be as little as 3,000 feet, or as great as 10,000 feet. An airplane traversing a microburst initially encounters the outflow on the front side, which increases the headwind component, causing the airplane to rise and its indicated airspeed to increase. Several seconds later, the headwind component begins decreasing and the airplane traverses the central core downdraft, "which can be very strong." Finally, the airplane encounters the back side of the microburst, and the tailwind component begins to increase, causing the airplane to sink and its indicated airspeed to decrease. "The time across this whole feature is anywhere from 20 to 40 seconds. That's not very long and can

20/ Fujita, T. Theodore (1985): The Downburst - Microburst and Macroburst.

21/ Aircraft Accident Report--"Pan American World Airways, Inc., Clipper 759, Boeing 727-235, N4737, New Orleans International Airport, Kenner, Louisiana, July 9, 1982" (NTSB/AAR-83/02).

create serious performance problems for an airplane. . . ." Assuming that the microburst's horizontal outflow winds are 30 knots, then during the 20 to 40 seconds required to traverse the area, an airplane would encounter a 60-knot horizontal windshear.

The project director testified that during JAWS, "We found that for about 75 microbursts, the average [wind speed spread] across it was 47 knots. . . The average microburst for an airplane is very severe. The wind differential across the . . . microburst [encountered by the Pan Am flight at Kenner] was about 47 knots.' He also testified "half the ones we looked at were stronger than [47 knots]." During JAWS, researchers had measured microburst wind differences in the 65-knot range, and "found one up here in the almost [one] hundred-knot range."

The project director testified that the LLWAS system "does a good job with gust fronts. We found in an analysis of our work in Denver in 1982 that it did not do a particularly good job with microbursts." The director cited the following reasons for this: a microburst tends to be smaller than the distance between sensors. The LLWAS is like a net, but the mesh is too coarse, and microbursts slip through. A lot of microburst action took place outside of the sensor locations, and "some sensors are sheltered, trees have grown up around them and they do an inadequate job detecting the wind." The project director concluded that the LLWAS is "a limited system but it can be improved and must be improved. It's the only system we've got right now, and let's make the most of it."

The CLAWS project was implemented by the FAA after a microburst windshear takeoff mishap at Stapleton Airport. Immediately following the mishap, the FAA contacted the National Center for Atmospheric Reseach (NCAR) in Boulder, Colorado, and asked if they would use Doppler radar to protect Stapleton Airport. Although the NCAR microwave pulse Doppler radar was located about 18 miles northwest of the airport, they tried to protect or cover a 5 nmi radius around Stapleton Airport with pulse Doppler radar. (Doppler radar can, in addition to detecting precipitation, measure tne velocity of the scatter echo of precipitation and other aspects of the atmosphere; it measures any component of motion perpendicular to the direction of its antenna and, therefore, can measure the speed of the winds within a weather cell.) During the CLAWS project, meteorologists were on duty in the radar room and in the tower cab, and were passing information directly to ATC and "hence, to pilots." The meteorologists used the Doppler radar to locate the microburst, estimate the differential shear across its diameter, provide a warning to the controller, which the controller would read to the pilot. (For example, weather radar indicates a microburst 2 miles north of Stapleton. Windshear may be 55 knots). The project director testified that they issued 30 microburst advisories in 45 days to 30 pilots; 7 pilots rejected the approach and executed a go-around.

In addition to the nowcasts based on the Doppler radar information, the project also issued a daily forecast of microburst probability. The forecast was based on analysis of the dry adiabatic lapse rates 22/ and the presence of moisture aloft in the atmosphere. The project director testified that the forecast was 80 percent accurate in determining that a microburst would occur near Denver that day. The forecast was delivered to the weather service and was distributed nationally every morning the

22/ The rate at which unsaturated air moving upward or downward cools or warms. The rate is independent of the temperature of the mass of air through which the vertical movements occur.

forecast was made. The project director testified that, although they cannot pinpoint 12 hours in advance where a microburst will be, they can identify the days "where a microburst is likely to occur for the dry high (cloud)-base type cases." He then testified that "we do not yet know how to forecast the conditions for a microburst in the heavy wet Southeast or humid regions of the United States."

A NOAA research scientist testified that the microburst problem is far from being solved. He testified that not all thunderstorms produce significant outflow winds nor do they produce microbursts. In addition, the potential for a microburst cannot be predicted based on the intensity of the weather echo. Since present-day NWS radar can only measure the intensity of the precipitation contained in the cell, he testified that he did not know of any technique available to the NWS radar specialist that would allow him to determine which convective echo on his radar would produce a microburst. He testified that the Doppler radar is the best available sensor to detect the presence of a microburst. The JAWS and CLAWS project director testified that "we found out . . . microbursts were enormously detectable with Doppler radar."

The research scientist testified that the research data showed that microbursts develop so rapidly and the responses are so transient that two airplanes, one following another through the microburst see entirely different things. He also testified that the JAWS data showed that, in general, "the microburst as seen by Doppler radar has a lifetime on the order of five minutes or longer, but not over ten minutes."

In addition, the research scientist and the JAWS director testified that the research data also indicate that the descending column of air in the microburst may produce horizontal vortices along its boundary with the environmental air.

The testimony at the Safety Board's public hearing disclosed that past and present microburst research has had very little impact on NWS operations and that formal training concerning research results had not been implemented.

NOAA has been involved in developing microburst forecasting techniques based on JAWS data for about 4 years. Although these techniques show great promise, for the most part this information and formal training to use these techniques have not been provided to operational meteorologists. The Safety Board believes that every effort must be made to ensure that pertinent information developed from microburst research is provided to operational meteorologists, and that formal training programs based on this information be implemented as soon as possible.

1.16.2 Wind Field Analysis

The microburst phenomena is often a part of the evaporation-condensation process which produces cumulonimbus clouds, heavy rainshowers, and thunderstorms. The windshear results from the convective movement of the air wherein low-level air heated by the ground rises and is replaced by cold air descending from aloft. The low-level wind condition is analagous to pointing a high-pressure air hose at the ground; the vertically descending air fans out in all directions.

When a microburst is encountered during a landing approach, the airplane will typically experience an increasing headwind, a downdraft, and a decreasing headwind in rapid succession as it passes beneath the outflow and descending air column. The increasing headwind will be recognized as the indicated airspeed increases suddenly and the airplane tends to rise above the glidepath. However, this apparent increase in airplane performance is shortlived as the airplane enters the downdraft and encounters the decreasing headwind caused by the reversal in the direction of the outflow. The rapid reversal of wind direction and speed produces sudden changes in the airplane's angle of attack and airspeed, which may reduce the airspeed far below the initial stabilized airspeed. The reduced airspeed will result in reduced vertical lift, causing the airplane to accelerate downward. Furthermore, the airplane's longitudinal stability will cause the airplane to pitch nose downward as it attempts to reacquire its trim speed equilibrium. The extent to which the airplane's flight path changes depends upon the severity of the windshear and the pilot's reaction with flight controls and engine thrust. The microburst might also create horizontal vortices which produces sudden changes of vertical wind speeds to further upset the longitudinal stability and perhaps the lateral and vertical stability of the airplane, exacerbating the pilot's control task.

At the Safety Board's request, the Lockheed California Company and the National Aeronautics and Space Administration (NASA) analyzed the information from flight 191's DFDR to determine the horizontal and vertical wind velocities affecting the airplane's performance during the instrument approach to the DFW Airport. The computations performed during this analysis were based on the following general assumptions:

- the weight and configuration of the airplane at the start of the ILS approach;
- the weather conditions at the DFW Airport at the time of the accident; and
- engine and airplane performance parameters derived from Rolls Royce and Lockheed documentation.

In determining the wind field penetrated by flight 191 during the approach to DFW Airport, the airplane's inertial flightpath was reconstructed based on data retrieved from the airplane's three accelerometers. The inertial flightpath was then compared with flightpaths constructed from radar data retrieved from the Fort Worth ARTCC's National Track Analysis Program (NTAP). The inertial flightpath overlay showed good correlation with the NTAP flightpath and the transponder altitude readout.

The three-dimensional, along-track wind field transited by flight 191 was reconstructed by comparing an inertially reconstructed flightpath to the air data information provided by the DFDR.

The "along flightpath winds" developed by NASA and Lockheed correlated reasonably well. Both analyses revealed that flight 191 penetrated a divergent wind field whose pattern resembled a microburst wind field pattern. Flight 191 encountered an initial increasing headwind, followed by a downdraft and a series of updrafts and downdrafts, in the presence of an increasing tailwind (decreasing headwind).

The general pattern shown in the analyses indicates that flight 191 encountered a strong downflow for a period of 20 seconds, followed by a series of rapid changes in vertical wind direction spaced about 5 seconds apart. In the period of the major downflow, the airplane experienced downdrafts from about 6 knots to about 24 knots. As the airplane entered the downflow, the headwind increased from about 10 knots to a maximum of 27 knots. Then, during a period of 26 seconds, there was a change to a 40-knot tailwind. Based on the rotation of the horizontal wind direction, the source of the downflow appeared to have been to the west of the flightpath.

A control column force analysis performed by Lockheed showed that a 22-pound push force was applied to the control column about 12 seconds before initial touchdown. Over the next 4 seconds, the forces were reversed, and by 8 seconds before impact, a 25-pound pull force was being exerted. Over the next 7 seconds, the forces again reversed and by 1 second before impact a 10-pound push force was being applied. During the last second the push force was decreasing.

At the Safety Board's public hearing, a NASA Aerospace Engineer amplified the manner in which the wind analysis was performed. He testified that both Lockheed and NASA used a similar analysis approach and that the results of the two analyses were "generally . . . the same."

The aerospace engineer testified that NASA also used the DFDR data to determine whether there had been any degradation of airplane performance due to heavy rain. When the lift generated by the airplane was compared with lift performance based on good airplane test data, no significant differences were identified between the predicted lift and the measured lift. He testified, "In terms of lift, there does not seem to be any performance degradation." He also testified that, because their work on drag performance had not been completed, they could not talk about drag with the same degree of confidence. However, he said that "we do not see any drag values out of order relative to what we'd expect. At the moment, we see no performance degradation." Later analysis of the airplane's drag performance substantiated this conclusion.

With regard to the rainfall rate encountered by flight 191, data showed that the maximum convective rate associated with a VIP level 4 echo (intensity = 49 dBZ) is about 3.7 inches/hour. A rain gauge located just west of the initial impact point had collected about 0.9 inch of rain in a 15-minute period, a rate of 3.6 inches/hour. Just before 1810, the RVR (runway visibility range) on the touchdown end of runway 17L had decreased to 1,600 feet. Calculations of rainfall rates based on RVR values 23/ indicate that a 1,600-foot RVR corresponds to a rainfall rate of 12.6 inches/hour. The evidence indicates that the rainfall encountered by flight 191 probably fell at the rate of at least 4 inches/hour.

NASA also evaluated how the use of different pitch attitude histories would have altered the airplane's flightpath through the windshear. The evaluation had two objectives: first, to determine if the derived wind field exceeded the airplane performance limits; and second, to test the windshear recovery technique requiring the pilot to rotate the airplane to a target pitch attitude, hold that attitude unless persistent activation of the stall warning stickshaker occurs, then reduce the pitch attitude enough to end the stickshaker activation.

The aerospace engineer testified that this was "in large part, an academic exercise, because . . . if the newly generated flightpath was a significant distance from the path on which flight 191's flightpath winds were measured, then our assumption regarding the use of flight 191's winds, "becomes less and less valid." He testified that if a flightpath quite close to that of flight 191's is assumed, then the assumption of the same winds to produce the new flightpath is "reasonably valid." Therefore, a series of pitch attitudes ranging from 15° to 2° nose-up were examined.

23/ Dietenberger, M.A., Haines, P.A, and Luers, J. K., "Reconstruction of Pan Am New Orleans Accident." Journal of Aircraft, Vol. 22, No. 8, August 1985.

The lowest alternate path examined during this exercise cleared the ground by 100 feet. This path was generated by allowing the airplane to pitch down as it did 14 seconds before impact but arresting the downward pitch at 2° nose-up, maintaining that attitude, "and then pulling up at a very modest rate toward the end of the period." The 15° nose-up pitch attitude produced a flightpath well above that of flight 191; however, the aerospace engineer testified that the assumption of the same winds for that flightpath was "very sketchy."

According to the engineer, the 2° nose-up flightpath "did not result in any increase of any peak angles of attack .... and it resulted in only a few knots change in the airspeed." He testified that, based on the fact that the lowest alternate flightpath cleared the ground, "we could deduce ... the airplane physically had the performance capability to fly a path that missed the ground." The facts show that the airplane initially touched down "with a very modest descent rate. It came very close to missing the ground, and it takes a ... very small path differential ... to start .. a slight climbing path at that particular point [initial touchdown]." Because of the loss of DFDR data after the initial touchdown, the aerospace engineer testified that, "Beyond [the point of initial touchdown] with no record and no information we can't deduce what would go on after that. There might be a terrific tailwind at that point, or a terrific headwind. You can only work with what you've got."

The aerospace engineer also testified that the DFDR information indicated that the flight was experiencing "unusually heavy turbulence" during the last portion of the descent. At one point, about 15 seconds before initial impact, the airplane rolled 20° right and the control wheel was deflected full left to recover, which, "strongly suggests flight through (or) pretty close to the center of a vortex flow."

The NASA computations showed three angle-of-attack peaks during the last 15 seconds of the flight. The first peak occurred about 15 seconds before initial impact and had a "brief spike" slightly above 21°. Since Lockheed data show that the stall warning stickshaker will activate at an angle of attack of 19° plus or minus 1/2°, the aerospace engineer testified that the 21° spike:

> would provide a one-second interval of stickshaker.
>
> The second peak (9 seconds before impact) ... gets to about a 15° angle of attack which is ... three or four degrees below stickshaker, I wouldn't expect a stickshaker there.
>
> The third peak during the final pull-out (5 seconds before impact), is about 18 1/2. Giving allowance for slight errors, tolerances in the angle of attack device, there might have been a very brief excitation of (the stickshaker) ... less than half a second.

1.16.3 Airplane Performance

Because the recorded information from the DFDR contained, in addition to airplane performance data, the control inputs made by the pilot, the Safety Board was able to determine and analyze the pilot's response to the derived winds.

The performance data indicated that the flight proceeded uneventfully until the final 47 seconds of the flight. The airplane was descending through about 800 feet AGL, on the ILS glideslope, at 150 KIAS (Vref + 13 KIAS), and holding a nose-up 4.5° pitch attitude.

Between 1805:05 and 1805:19, the airplane encountered an increasing headwind component. The onset of the increase was gradual, but between about 1805:12 and 1805:19, the headwind component increased at a rate of about 2.7 knots/second. During this 14-second period, the airplane accelerated to about 173 KIAS, and the first officer retarded the throttles. By 1805:15, despite the instructions in the Delta L-1011 Pilot Operating Manual (POM), which states, "do not unspool the engines," all three engines were either at, or very near, flight idle EPR and remained at that thrust level until 1805:22. During the first part of this period, the first officer also applied a gradual nose-down control input. By 1805:14, the pitch attitude reached 1.3° nose-up and then began to increase as the first officer began to apply nose-up control inputs. At or shortly before 1805:19, the airplane encountered a strong downdraft. The vertical winds changed from a 10-fps updraft to a 20-fps downdraft. The first officer's response was to apply further nose-up control input and the pitch attitude increased to about 7° nose-up. At 1805:19, the captain warned the first officer, "watch your speed," and 1 second later the airplane entered the heavy rain.

From 1805:19 to 1805:29, the headwind decreased by about 25 knots and the downdraft increased from about 18 fps to more than 30 fps. Thrust was near flight idle during the first 6 seconds of this period and, combined with the loss in headwind component, resulted in a loss of about 30 knots of airspeed. During the last 4 seconds of this period, thrust was increased to within 0.01 to 0.02 of go-around power. (Delta's procedures require the flightcrew to ascertain the go-around or missed approach EPR during the approach check and to set the indicator or EPR bug on each EPR indicator to the computed setting. The CVR transcript showed that this checklist item was completed at 1757:13. The go-around EPR for this approach was 1.48 EPR. Assuming that the throttles were pushed full forward to their stops, the maximum available EPR would have been about 1.53 EPR.) Even as thrust was being applied, airspeed continued decreasing to about 129 knots, for a total loss of 44 knots in 10 seconds. Also, pitch attitude was increased to about 15.7° nose-up to maintain glideslope and counter the strong downdraft. At 18:05:29, the decreasing trend of the headwind again reversed itself, and along with a high thrust condition, resulted in a rapid increase in airspeed from about 129 to 147 KIAS. At 18:05:31, thrust was reduced from an engine pressure ratio of 1.47 to 1.33 and by 1805:35 the airspeed decreased to 140 KIAS. The DFDR data showed that between 1805:19 and 18:05:35, flight 191 had essentially maintained the glideslope despite airspeed fluctuations of +20 knots to -44 knots and downdrafts from 15 to 40 fps during the preceding 32 seconds.

At 1805:35, flight 191 encountered an atmospheric disturbance which could best be described as severe and localized. Within 1 second, large variations in wind components along all three axes of the aircraft were noted. Indicated airspeed decreased from 140 to 120 knots, the vertical wind reversed from a 40-fps downdraft to a 20-fps updraft, and a severe lateral gust struck the airplane as well. This gust resulted in a very rapid roll by the airplane to the right, requiring almost full lateral flight control authority to level the wings. Of equal importance was that the airplane's angle of attack increased from 6° to approximately 23° degrees, and most likely increased more rapidly, and to a higher value, than recorded by the DFDR because of the rate-limited angle of attack sensors. Although the sound of the stickshaker was not heard on the CVR, the stickshaker probably activated, albeit for only about 1 second. This severe environment that flight 191 encountered most likely is what prompted the captain to say, "Hang onto the (non-pertinent word.)" It was also about this time that engine thrust was applied.

The DFDR data showed that the power began increasing on the engines at about 1805:36. By 1805:44, all three engines had reached about 1.53 EPR and they remained at that thrust level until the airplane touched down the first time.

During the next 3 seconds, in response to the pitching moments induced by the much higher-than-trim angle of attack and the pilot's nose-down control column deflection, a rapid nose-down pitch rate developed. By 1805:39, the airplane's pitch attitude was 3.6° nose-up, and continuing downward. Also at this time, the vertical wind reversed again from an updraft to a strong downdraft. Between 1805:35 and 1805:48, the derived wind calculations showed six strong reversals in the vertical wind component. The strong downdraft, combined with the airplane's rapid nose-down pitch rate, induced a sudden reduction in angle of attack to near zero. In fact, a vertical acceleration of +0.3 g was recorded by the DFDR. As a result, the airplane began a rapid departure from the glideslope.

At 1805:40, the DFDR data indicated a large forward-from-trim deflection of the control column. The resultant pitching moment was sufficient to overcome the nose-up moment resulting from the low angle of attack prior to 1805:42, and the nose-down pitching rate began to increase. At 1805:42, the vertical wind reversed again, resulting in an angle of attack increase from 5° to 14° degrees in approximately 1 second. This combination of nose-down, pilot-induced control column force and the above-trim angle of attack resulted in a peak nose-down pitching acceleration at 1805:43. Both of these pitching moment contributions reversed after 1805:44, but not before inducing a nose-down pitch rate of about 5° per second as the pitch attitude decreased through 5° nose-down.

Beginning at about 1805:40, a large increase in the tailwind component was recorded. Due to the 30-knot tailwind, airspeed did not increase beyond about 135 knots despite maximum thrust and a steepening flightpath. By 1805:44, the airplane was at 420 feet AGL, its descent rate was about 3,000 feet per minute, its airspeed began to increase, and it was in a strong downdraft. At 1805:44, the CVR recorded the first GPWS alert, and 1 second later, the captain called "TOGA." The low angle of attack resulting from the low pitch attitude (7.4° nose-down), and the strong downdraft combined with a substantial nose-up control deflection, produced a large nose-up pitching moment. This reversed the pitch attitude trend, but not until pitch reached about 8.3° nose-down.

At 1805:46, with the airplane at about 280 feet AGL, its descent rate was close to 5,000 feet per minute. By 1805:48, the vertical wind changed from about 40-fps downdraft to about 10-fps updraft. This reversal in wind component, combined with a substantial nose-up pitch rate, increased angle of attack rapidly. At 1805:48, a +2.0 g vertical acceleration was recorded. It is probable that, for about 1 second, the stickshaker activated for the second time, and pitch attitude peaked at 6° nose-up. At 1805:50, another downward trend in pitch is noted, so that, about 2 seconds before initial ground contact, a pitch attitude of about zero degrees was recorded. In the last second before ground contact, pitch increased to approximately 3.1° nose-up.

From 1805:45, until initial ground contact at 1805:52, no further longitudinal wind changes were noted. Accordingly, the airplane's airspeed increased steadily to about 170 KIAS at touchdown.

Some DFDR data were lost in the 4 seconds subsequent to initial touchdown. It is estimated that the vertical descent rate at touchdown was on the order of 10 fps, certainly not enough to compromise the airplane's structural integrity. A nose-down control deflection and a reduction in engine power were also observed during this 4-second period.

1.16.4 Flight Director System Study

The Safety Board requested the Lockheed and Collins Companies to analyze the pitch commands that would have been displayed by the flight director system's pitch command bar during the descent. The completed analysis depicts the last 52 seconds of the flight before initial ground contact.

The simulation of the final seconds of the flight begins with the airplane on the glideslope, 1,045 feet AGL, and 52 seconds from initial impact time. The simulation was operated in a three-DOF (degree of freedom) mode. The horizontal and vertical winds and the DFDR-recorded EPRs averaged across the three engines were applied by a function generator.

The flight director was in the Approach/Land mode until TOGA was selected. The reconstruction showed that the airplane did not descend below the glideslope until 1805:42, 10 seconds before initial impact. While the flight director was in the Approach/Land mode, the system's glideslope-based logic was providing pitch commands to maintain the airplane on the glideslope and, until 1805:42, the airplane's pitch attitude corresponded essentially to the attitude commanded by the pitch command bars. During the next 2 seconds, as the airplane descended below the glideslope, the pitch command bars moved upward to command a nose-up pitch correction. When TOGA was selected, 7 seconds before initial impact, the airplane was over 3 dots below the glideslope and descending at a rate of about 3,000 feet per minute. The airplane's pitch attitude was 8.3° nose-down and the pitch command bars were commanding an 11.3° nose-up pitch correction.

The Delta L-1011 POM advises flightcrews to use the flight director's TOGA mode to initiate and complete a missed approach from a landing approach. In the TOGA mode, the flight director computers sense the airplane's configuration engine thrust and angle-of-attack, and will position the command bars to command an angle of attack that will maintain the airspeed at or above 1.25 Vs. 24/ Angle of attack is controlled by pitch attitude, and the flight director logic limits the nose-up and nose-down pitch attitudes between 17.5° and -1.2°, respectively. In the TOGA mode, the flight director will, if necessary, sacrifice altitude to maintain the airplane's airspeed at or above 1.25 Vs. At 324,800 pounds, 33° flaps and slats extended, and gear down, 1.25 Vs was 131 KIAS. At 1805:45, when TOGA was selected, the airspeed was about 137 KIAS. During the 7-second interval, the airspeed increased to about 170 KIAS and the rate of increase was essentially linear.

About 1 second before TOGA was selected, the first officer had begun a nose-up correction. At 1805:46, 1 second after TOGA was selected, the airplane's pitch attitude had increased from 8.3° to 7° nose-down and the command bars commanded an 18° nose-up pitch correction. During the next 2 seconds, the first officer continued to raise the nose of the airplane; however, at 1805:48, 4 seconds before initial impact, the airplane's angle of attack increased suddenly from about 3° to about 16°. The airplane's pitch attitude was 5° nose-up and the command bars were commanding a 10° nose-up correction. Over the last 4 seconds before initial impact, the airplane's pitch attitude decreased from 5° nose-up to 0° and then increased to 2° nose-up. The pitch command bars lowered and, although they were within 0.13 inch of being centered, they were still commanding a 5° to 6° nose-up correction to an 8° nose-up pitch attitude when the airplane touched down.

24/ The stalling speed or the minimum steady flight speed at which the airplane is controllable.

1.16.5 Weather Analysis

NOAA provided the Safety Board with an analysis of the weather conditions affecting the landing approach of flight 191. The NOAA analysis, conducted at the request of the Safety Board, was based on its analysis of large-scale meteorological patterns, Geosynchronous Operational Environmental Satellite (GOES) data, weather radar data, airplane weather radar data, flight 191's DFDR data, and an examination of eyewitness accounts of the weather.

The analysis states that the data contained in the NASA wind field analysis:

> shows that the aircraft penetrated the main downdraft of the microburst at 550-850 feet AGL. The aircraft survived the downdraft only to crash in the outburst, or low level outflow of strong winds which contained not only a strong tail wind but a series of three strong wind vortices which were parts of vortex rings which circled the main downdraft.

The analysis states that, "The microburst was in the process of just reaching the surface when Delta 191 entered it."

The analysis states that the thunderstorm involved in the crash was:

> one of a line of discrete cells which extended into the DFW area from the northwest where the line joined a more extensive and intense. . . complex of thunderstorms along the Red River [about 100 nmi north of DFW Airport.]

The analysis also stated that the "thundershowers" in the immediate DFW Airport area were produced by two storms--Cells "C" and "D"--and that the second storm (Cell "D") was much more severe. The analysis stated, "Further, the first or weaker parent storm (Cell "C") was dissipating just as the second, more intense offspring, was about to become violent."

1.16.6 Flight Attendant's Jumpseat Restraint Systems

Because of the difficulties encountered by the flight attendant in trying to release the restraint system at the R-4 jumpseat, the Safety Board examined the restraint systems at the R-3, R-4, and L-4 flight attendant jumpseats. The other jumpseats had been damaged too extensively to draw any valid conclusions concerning their precrash condition.

The examination of the R-4 and L-4 systems showed that the seatbelt straps were badly worn and damaged, and the shoulder harnesses were stretched and worn, and had been abraded by chafing. In addition, the restraint systems had not been installed in accordance with engineering specifications. The restraint systems had been manufactured in early 1982.

The restraint systems' worn and abraded straps were taken to CAMI and tested for tensile strength with the following results:

> The R-4 seat's left seatbelt strap failed at 1,300 pounds tension for an undetermined reason in the area where it had been jammed inside the adjuster. The strap was designed to a minimum breaking strength of

4,000 pounds; however, FAA Technical Standard Order (TSO) specifies a minimum seatbelt breaking strength of 2,250 pounds and that the entire seat belt assembly (all straps, hardware, and attachments) must be able to withstand a minimum 1,500-pound load without failure.

The R-4 seat's right seatbelt strap failed in the damaged area at 1,850 pounds of tension and below the manufacturer's and the TSO's minimum breaking strength. However, despite this failure, the minimum 1,500 pound load required to fail the entire assembly would not have been compromised.

Each of the L-4's seatbelt straps failed at 2,200 pounds in their damaged areas.

The R-4 jumpseat's right shoulder strap failed in the damaged area at 3,400 pounds or 600 pounds below the manufacturer's minimum standards.

The investigation also disclosed that neither the airline, the FAA, the manufacturer of the restraint system, or the supplier of the strap materials had published guidelines that could be used to determine when the amount of damage or wear would require the replacement of the restraint system's straps.

* 1.17 Other Information

2. ANALYSIS

2.1 General

The airplane was certificated, equipped, and maintained in accordance with Federal regulations and approved procedures. There was no evidence of a malfunction or failure of the airplane, its components, or powerplants that would have affected its performance.

The flightcrew was certificated properly and each crewmember had received the training and off-duty time prescribed by FAA regulations. There was no evidence of any preexisting medical or physiological conditions that might have affected the flightcrew's performance.

The ATC controllers on duty in the DFW Airport TRACON at the time of the accident were certificated properly and each controller had received the training and off-duty time prescribed by FAA regulations. All of the controllers providing ATC services to flight 191 were full performance level controllers.

The NWS meteorologists were qualified, and the contract weather observer at DFW Airport was certificated by the NWS.

Based on the evidence, the Safety Board directed its attention to the meteorological, airplane performance, air traffic control, and operational factors that might have caused the airplane to descend and crash, and to occupant survival. The

*ICAO Note.— Section 1.17 was not reproduced.

meteorological evidence relevant to this accident included the weather conditions at DFW Airport at the time of flight 191's approach, the weather information provided by the NWS to ATC, the weather information provided by ATC to flight 191, and the flightcrew's use of the airplane's weather radar system. For continuity and clarity, aspects of the latter two weather-related areas--the weather information provided by the ATC to flight 191 and the use of airplane weather radar systems--are discussed during the Safety Board's examination of ATC and operational factors.

2.2 Meteorological Factors

Weather at DFW Airport.--On final approach to runway 17L at DFW Airport, flight 191 penetrated a weather cell containing a thunderstorm with a heavy rain shower. Because of the evidence that two weather cells (Cells "C" and "D") were present north of runway 17L, the Safety Board examined the possibility that Cell "C" might have masked Cell "D" from flight 191's flightcrew.

At 1752, the Stephenville weather radar data indicated that a weak (VIP level 1) weather echo (Cell "D") developed about 2 nmi northeast of the approach end of runway 17L. The center of the echo was about 6 nmi northeast of the end of the runway. This was the closest echo to the approach end of runway 17L and at 1752, it contained only light rain showers.

At 1800, when the Stephenville radar specialist had returned to his radarscope from other duty requirements, the weather echo had intensified to a very strong echo (VIP level 4). At 1804, the radar specialist called to inform the NWS Fort Worth Forecast Office of the presence of the echo, its intensity, and that its top was 40,000 feet. At or very shortly after 1805, flight 191 penetrated the rain shaft falling from this weather echo.

During the Safety Board's public hearing, the radar specialist said that another, weaker weather echo was located north of Cell "D" and about 6 nmi northeast of the airport. He testified that, based on the 1800 radar photograph, Cell "C" looked "like maybe a VIP [level] two [echo]," but could not state that the smaller echo would mask the larger cell from a southbound airplane. None of the ground witnesses who had viewed the north side of the storm described the presence of any clouds or any additional areas of precipitation in the vicinity of the north side of the storm. The captain of flight 539 following flight 191 testified that he was 5 to 6 miles behind flight 191 when flight 539 turned on final and that he kept flight 191 in sight until it entered the rain shower beneath the buildup. He also testified that he saw lightning in the area where he lost sight of flight 191. His first officer stated that when they turned on final, a cell containing "abundant lightning" was directly off the approach end of runway 17L, and he saw flight 191 "penetrate the cell." Based on the evidence the Safety Board concludes that the cell at the end of runway 17L was not masked from flight 191 by an intervening weather cell.

At 1803:58, flight 191 reported to the tower and stated that they were "in the rain," and at 1805:20, a sound similar to rain was heard on the CVR. Since that sound was not heard at 1803:58, the Safety Board believes that the rain did not intensify until 1805:20. At 1804:18, the first officer reported seeing lightning "coming out of that one." When questioned by the captain he again used the term "that one" to describe the origin of the lightning and then informed the captain that the lightning was "right ahead of us." The Safety Board believes that the language used by the first officer indicated that he was able to see the cloud or cell that was emitting lightning and that the flightcrew still had forward visibility until the rain intensified at 1805:20.

Wind Field Analysis.--The analyses of the airplane's performance and inertial parameters recorded on the DFDR conducted by both Lockheed and NASA were consistent and showed that the horizontal winds affecting flight 191 veered from an easterly to a northerly direction. During the descent, a maximum headwind component of about 26 knots was encountered at 754 feet AGL. The headwind component then decreased, changed to a tailwind, and the maximum tailwind component of 46 knots occurred near the first impact point. Since the airplane's ground speed was increasing at this time, it was probably still within the outflow at impact.

Based on the rotation of the wind direction along the airplane's flight path, the center of the outflow was located about 1,000 feet west of the airplane's ground track and 12,000 feet north of the approach end of runway 17L. Flight 191 encountered the northern edge of the outflow at 1805:14 when its headwind component began increasing rapidly. At 1805:14, the ATC radar plot showed flight 191 was about 9,900 feet from the first touchdown point and about 11,300 feet from State Highway 114. Since witness statements indicated the precipitation did not reach the highway until after flight 191 went across it, and since flight 191 was still within the outflow at first impact, the Safety Board concludes that the southern edge of the outflow was between the first impact point and the highway and about 11,000 feet from the northern edge of the outflow.

The wind field showed that flight 191 flew through the outflow of a thunderstorm. The horizontal dimensions of the outflow were about 11,000 feet (3.4 kilometers) and since the airplane's track passed close to the center of the outflow, the diameter of the outflow, assuming symmetry, was also about 3.4 kilometers. Based on its size, this outflow can be classified as a microburst. The vertical winds affecting the flight included a maximum downdraft of 49 fps, which occurred at 590 feet AGL followed at 560 feet AGL by the maximum updraft of 25 fps. Within the next 8 seconds, the airplane experienced a 22-fps downdraft, a 16-fps updraft, a 42-fps downdraft, and a 18-fps updraft.

The evidence indicates that flight 191 entered the microburst at 1805:14 and crashed at 1805:52. During that 38 seconds, it encountered a horizontal windshear of about 72 knots. In addition, the six rapid reversals of vertical winds and the 20° right-wing-down roll during the final portion of the descent showed that the airplane penetrated a vortical wind flow.

The LLWAS.--The Safety Board considered the possibility that the LLWAS did not function properly and that, given the location of the microburst, its alarm should have sounded earlier.

The LLWAS was recertified the morning after the accident. In addition, beginning August 12, 1985, and over the next 6 weeks, the wind velocity-measuring components of all the LLWAS's wind sensors were checked and recalibrated where required. All of the boundary-located sensors were found to be accurate. The centerfield sensor's wind direction-measuring components were accurate, but the sensor's speed-measuring components read 4 knots low; therefore, the LLWAS was more sensitive in computing any windshear alarm. Since the centerfield sensor was reading 4 knots low, a lesser magnitude of wind at the two northern sensors was required to produce the 15-knot vector difference required to place the system into alarm.

The LLWAS did go into alarm after flight 191 crashed. One controller stated that the alarm began as the rain moved across the north end of the field and by the time he checked the display, all sensors were in alarm. Other controllers stated that it did not sound until after the storm moved across the field, and that when they checked the display, all sensors were in alarm. Regardless, the LLWAS was operational and did alarm. Given the location of the microburst and the fact that the southern edge of the microburst's outflow was about 2,000 feet north of the northeast sensor when the airplane first impacted, the LLWAS could not have provided any timely windshear warning to the flightcrew of flight 191.

The Delta Air Lines Meteorology and Dispatch Departments.--The Delta dispatcher on duty had tried unsuccessfully to call up the Stephenville radar site on his Kavouras monitor at 1745 and 1750. Between 1750 and the time of the accident, he did not try to call Stephenville again. Since the dispatcher did not have any new or different weather information to provide to flight 191, he did not try to contact the flight as it approached DFW Airport, nor was he required to.

The Fort Worth Forecast Office.--The aviation forecaster on duty at the Fort Worth Forecast Office became aware of the storm cell northeast of DFW Airport about 1804, after he overheard the radar specialist at Stephenville describe the cell to the public and State forecaster. He then observed the cell on his television monitor.

The aviation forecaster testified that during the day he had watched numerous cells build to VIP level 4 and then dissipate without receiving any ground truth reports of thunder, hail, or winds that met the criteria for requiring an aviation weather warning. The cell northeast of DFW Airport did not, in his judgment, seem any different from those he had observed earlier, and therefore he decided not to issue an Aviation Weather Warning to DFW Airport.

The aviation forecaster testified that he considered the intensity of a radar weather echo to be "merely an indicator" of the severity of a storm and that, in the absence of ground truth reports attesting to the presence of thunder, hail, or both, he would not label a VIP level 4 radar weather echo a thunderstorm. Given the criteria for issuing an Aviation Weather Warning and the fact that, in the forecaster's judgment, Cell "D" did not seem to be different from the VIP level 4 echoes he had observed earlier, the Safety Board can only conclude that the aviation forecaster's decision not to issue an Aviation Weather Warning was reasonable.

In addition, except for Carswell Air Force Base, the Fort Worth Forecast Office was responsible for issuing Aviation Weather Warnings to all of the airports in the Dallas/Fort Worth metropolitan area, and none of these airports were depicted geographically on either the office's weather radar display or map overlays. Despite the fact that the aviation weather forecaster knew the location of DFW Airport, the Safety Board believes that all NWS offices that have an aviation weather warning responsibility should have the airports for which they are responsible clearly located on a map for each weather radar display in the office.

The Center Weather Service Unit.--The Fort Worth ARTCC's CWSU was staffed in accordance with the levels agreed upon by the FAA and NWS. On the afternoon of August 2, 1985, the CWSU was staffed by an NWS meteorologist and an assistant traffic manager serving as the weather coordinator. Since the ATC personnel assigned to the weather coordinator position are not trained or qualified to interpret the weather or to observe the CWSU's RRWDS, no one was available to monitor the RRWDS when the meteorologist went to the cafeteria for his meal break about 1725 until he returned about 1810, 4 to 5 minutes after flight 191 crashed.

The meteorologist, even if he is the only one on duty in the CWSU, is allowed a meal break in addition to those required for other personal needs. In this case, before leaving the CWSU, the meteorologist had assured himself that there were no thunderstorms threatening any of the airports in the Dallas/Fort Worth area and that the line of thunderstorms well east of Dallas, with which he had been concerned, was relatively stable. The radar photographs confirm his evaluation of the situation.

During the meteorologist's absence, Cell "D" developed and began to grow and intensify. At 1752, it was a small VIP level 1 radar echo. At 1756, Cell "D" was a VIP level 3 echo, and about 1800, the Stephenville radar specialist saw the echo and classified it VIP level 4. Given the 2-minute delay in receiving Stephenville data on the RRWDS, Cell "D" would not have been portrayed on the RRWDS as a VIP level 4 until about 1802. The CWSU meteorologist testified that, based on Cell "D's" location and rapid growth rate, he would have issued a CWA when it had intensified to a VIP level 4 if he had been on duty at the RRWDS and had observed the cell's development. However, if routine notification procedures were used, the CWA would have reached the TRACON and tower cab between 1807 and 1812, which was after flight 191 crashed. The CWSU meteorologist further testified that in this case he would have issued the CWA by telephone to the DFW tower supervisors. Had he done this, the CWA might have reached the DFW Tower about 1802 or 1803. ATC procedures require a CWA to be broadcast on all frequencies; therefore, assuming that the information was processed promptly, the TRACON and local controllers probably could have broadcast "an all airplanes on the frequency" weather alert between 1803 and 1805, possibly in time for the crew of flight 191 to receive it before they entered the rainshaft and microburst.

The Safety Board believes that the meteorologist's decision to take a meal break was understandable and not imprudent, given his assessment of the weather condition at the time. Further, the Board is not certain that, given his other responsibilities, the presence of the meteorologist at his station would have assured his immediate observation of the cell buildup. Finally, the Board is hesitant to accept this NWS-to-ATC-to-pilot communication channel as a primary circuit for observation and transmittal of rapidly changing dynamic weather conditions. Use of this channel presumes that the information telephoned to a tower facility can be immediately conveyed to the appropriate local controller and further transmitted to the appropriate flightcrew within several minutes or less. We believe this to be a false presumption in view of the controller's workload and total responsibility, and that more effective weather observations and communication capabilities are needed. This is, and has been, the basis for Safety Board recommendations that address the need for weather information to be directly available at the local controller's stations and ultimately for providing a ground-to-air data link.

Nonetheless, until the ATC towers are better equipped and staffed to define and disseminate to flightcrews the weather in the immediate vicinity of the airport, the NWS and CWSU systems remain the key elements in providing severe weather information to flights approaching and departing the airport. Therefore, the Safety Board believes that immediate steps can be taken to improve the efficiency of the system. The Board believes that both the CWSU and major tower facilities must be sufficiently staffed with meteorologically qualified personnel to continuously monitor weather radar and to facilitate the immediate communication of severe weather information to the controller who is in radio communication with flights close to or in the area of the weather.

There are 20 CWSUs throughout the contiguous United States and one in Alaska. The Safety Board's investigation disclosed that some of these offices have obsolete, and in some instances inadequate equipment to display and interpret satellite and radar information. Because of the importance of the CWSUs to aircraft safety, the Safety Board urges the FAA to ensure that the CWSUs have the best possible data and display capability with which to ensure the safety of the National Airspace System.

2.3 Air Traffic Control

The major ATC issue requiring examination by the Safety Board was the weather dissemination procedures of the ATC controllers who had provided services to flight 191. However, before proceeding with any analysis of that issue, the following additional issues required Safety Board examination.

The equipment used by the ATC controllers was functioning properly at the time of the accident. All positions within the TRACON were staffed properly, and the tower cab's assigned supervisor was working the local control east position at the time of the accident. Examination of the facility showed that tower cab supervisors routinely work control positions in order to maintain proficiency, to train developmental controllers, and to provide relief during dinner periods. In this instance, there was another supervisor qualified to serve as a supervisor in the tower cab. Though he was not assigned officially to serve in this position, he did perform voluntarily some of the routine tasks that devolve on the tower team supervisor. The Safety Board found no evidence to indicate that any required duties had been omitted.

Runway Selection.--The tower supervisor is primarily responsible for selecting the active runway and, according to Paragraph 3-60 of the Controllers Handbook, the controller will use "the runway most nearly aligned with the wind." During the 20 minutes before the accident, the winds were about 10 knots or barely exceeding that value. The wind direction, with regard to the parallel 17/35 runways, was essentially a direct 90° crosswind which, from time to time, varied about 20° either side of the 90° crosswind. The tower cab's supervisor testified that before he was relieved at 1809 the winds had been variable from 60° to 90° and "with a 30° variance like that, in my estimation we still were favoring landing south." Given the light wind speed, the winds provided a very small tailwind component, if any. The Safety Board believes that the 60° wind direction may have favored a north landing; however, given the low speed and the varying direction of the wind, and the other conditions involved in changing the direction of traffic, we find little if any evidence to indicate that the supervisor's decision to continue south-landing operations was imprudent or improper.

The Safety Board recognizes that the LLWAS centerfield sensor used by the controllers for runway surface wind information was providing speeds that were 4 knots below the actual wind velocity. However, this fact was not known to the controllers; therefore, their reliance on the centerfield sensor to provide wind information to pilots and for runway selection criteria cannot be faulted. The contract weather observer's wind sensor, which recorded wind velocity but not direction, was located within 40 feet of the centerfield sensor. Until 1750, the weather observer's sensor recording showed that the wind speeds were at or below 5 knots. Between 1750 and 1810, the wind speeds averaged about 10 knots, while the prevailing wind direction during that period, as reported by the controllers, varied from 60° to 90°. Consequently, the resulting average crosswind component was about 9.5 knots, although the headwind and tailwind components varied from about 1 knot to 3.5 knots, respectively. These three wind components were within the demonstrated and allowable wind limitations for takeoff and landing of virtually all air carrier aircraft operating at DFW Airport. If they were not, or if any pilot operating at the airport was uncomfortable with the reported surface winds, it was the pilot's responsibility to inform the controllers of his objections and intentions. One flightcrew did question the direction of landing; however, after being informed of the varying surface winds, the captain elected to continue and to land without any further objection or report of concern.

Airspeed Adjustments.--The Controllers Handbook did not prohibit controllers from requesting a turbojet airplane to slow to 150 KIAS. All that is required is to preface the request with the phrase "If practical." The controller did not do so and thus failed to comply with the provisions of the Controllers Handbook. Nevertheless, with or without the use of the proper terminology, if the pilot cannot comply with the request, either because of airplane operational limitations or weather, it is his duty to inform the requesting controller that he cannot comply. Since the captain of flight 191 accepted the speed adjustments without complaint, the Safety Board must assume that he did not consider them a threat to the operation or safety of his airplane, and the Board concludes that the speed adjustment requests were not causal to the accident.

Because the runway 17L ILS approach's outer marker is located 5.1 nmi from the end of the runway, the controllers were authorized to use speed restrictions for separation until flight 191 reached the marker. The evidence showed that the last speed restriction requested was issued before flight 191 reached the outer marker.

Radar Separation.--The applicable separation standard between flight 191 and the Learjet was 3 nmi and the traffic controllers stated that the standard separation never compromised. Although the LCE controller's BRITE display had 1 nmi markers along the approach course, it is difficult simply to look at the radarscope and determine separation to the nearest tenth of a mile.

The recorded radar data from the Fort Worth ARTCC indicates that a loss of separation between flight 191 and the Learjet occurred inside the ILS's outer marker. The minimum distance between the two airplanes was 2.5 nmi at 1804:47, increasing to 2.63 nmi at 1805:18. The maximum error tolerance in the recorded data was plus or minus 0.125 nmi. Based on these data, a loss of separation may have occurred; however, the Safety Board concludes that it had no bearing on the accident.

Automatic Terminal Information Service.--The weather contained in ATIS messages was taken from the contract weather observer's surface weather observations. The investigation confirmed that, pursuant to FAA policy, weather remarks contained in the airport's surface weather observations were not included in the ATIS message. For example, the remarks section of the 1751 surface weather observation stated that cumulonimbus and towering cumulus were located to the north and east of the airport. At 1800, ATIS message Sierra was issued. Except for the description of the cumulonimbus and towering cumulus clouds, Sierra contained the entire 1751 surface weather observation.

The FAA order describing the contents of ATIS messages states that weather data should or can include, where applicable, "other pertinent information." The FAA representative testified that "other pertinent remarks" refers to weather conditions which are not readily obvious and thus appropriate for an ATIS broadcast, such as tornados, thunderstorms, large hail, moderate to extreme turbulence, and light to severe icing. Therefore, ATIS Sierra as issued was in compliance with applicable FAA policies.

However, the Safety Board takes exception with the FAA position, noting that a thunderstorm would be a proper ATIS entry. Cumulonimbus and towering cumulus are convective clouds which can easily and very quickly become thunderstorms. Even without the presence of lightning and thunder, they should be avoided, and the Safety Board believes that the FAA should reconsider its position on this issue. The Safety Board also notes that the Federal Meteorological Handbook, No. 1, Table A3-8A, states that remarks concerning "cumulonimbus clouds" are significant to the air traffic controllers.

Given the timing of ATIS Sierra, flight 191 never received Sierra; therefore, the Safety Board concludes that the omission of the cumulonimbus and towering cumulus from the message played no part in causing the accident. By the time Sierra was issued, flight 191 was on a downwind leg for runway 17L, and the cloud area described in the 1751 surface weather observation should have been as apparent to the flightcrew as it was to the weather observer.

ATC Weather Dissemination.--The ATC controller is responsible to disseminate weather that he or she observed either visually or on radar pursuant to the limitations contained in the Controllers Handbook. The ATC controller also is responsible for ensuring that all significant weather messages, i.e., SIGMETS, PIREPS, CWAs, and such, are relayed on all frequencies if any part of the area described in the messages is within 150 miles of the airspace under the controller's jurisdiction. At 1800, on August 2, 1985, there were no such significant weather messages at the DFW Tower to relay.

The Terminal Area Approach Control.--Since the TRACON has no windows, the only sources of weather information available to personnel on duty would be weather information and messages from the NWS, the airport's surface weather observation, PIREPs, the observations of the tower cab controllers, and precipitation returns on the two radar systems. Since precipitation returns degrade the quality of the information needed by controllers to perform their first priority duty of traffic separation, ATC radar systems are not designed to enhance them and, in fact, incorporate circuitry which suppresses the intensity and decreases the area of the precipitation return, i.e. circular polarization. Thus, when a precipitation return appeared on the TRACON radarscope, other than knowing that the precipitation in the area was of sufficient intensity to be painted by the radar, the controller had no way to estimate the intensity of the precipitation creating the return. To classify the return area as a thunderstorm, he needed additional information from another source. At the time of the accident, the only information available to the FE and AR-1 controllers was the information on their radarscopes.

With regard to other sources of information, about 1800, the TRACON supervisor was told by a controller returning from a scheduled break that he had seen lightning near the airport. The returning controller did not locate the source of the lightning nor did the supervisor question the controller for details. The supervisor merely viewed the evidence of the presence of lightning as a potential threat to the TRACON's commercial electrical power and ordered the facility switched to back-up power, a routine precaution under these circumstances. The traffic control positions were not informed of the returning controller's observation. Given the fact that other and more authoritative sources of weather information such as the tower controllers, pilots, and NWS observers had not reported the existence of severe weather in the immediate vicinity of the airport, the Safety Board does not consider the actions of the radar room supervisor unreasonable.

The first description of the weather to the north of the field was received by the TRACON from an outside source at 1803:58 when the area supervisor in the tower cab called the TRACON and reported "heavy rain off the approach end of both runways, just for your information." There was no mention of either lightning or thunder.

Both the FE and the AR-1 controllers reported the presence of the rain shower off the north end of runway 17L. At 1756:28, the FE controller issued an "all aircraft listening" transmission describing a "little rain shower just north of the airport . . . they're starting to make ILS approaches. . . ." This transmission was received by flight 191. At 1759:44, the FE controller told flight 539 "there's a little bitty thunderstorm sitting right on the final; it looks like a little rain shower." Flight 191 did not receive this transmission.

The Controllers Handbook contains recommended phraseology for controllers to use to describe the appearance of weather echoes on their radars. The phraseology is designed to make the pilots aware of the areas of precipitation depicted on their radarscopes, not to analyze what is causing the return or its intensity. If the controllers are provided more specific information from either NWS, CWSU, or PIREPS concerning the depicted areas, they may use that information to describe the radar depiction. Since the FE controller had not received any reports of a thunderstorm, he testified that his use of "little bitty thunderstorm" at 1759:44 was improper. He also testified that he normally used the words light, moderate, or heavy to describe precipitation intensity and he used "little" with "rainshower" to describe the size of the precipitation area.

The CVR transcript showed that the FE controller informed flight 191 of the weather lying off the north end of runway 17L. The Safety Board believes that the use of the adjective "little" might have, despite the controller's stated intention, been interpreted by the flightcrew as a description of the severity of the rainfall rather than the size of the precipitation area. However, the Safety Board also notes that the 1756:28 transmission should have indicated that the shower's intensity had decreased the visibility in the area to the point that ILS approaches were now required to land at DFW Airport.

The ATC transcript showed that the AR-1 controller had, at 1803:30, broadcast a message that the airport was experiencing some variable winds due to a shower just beyond the "north end of DFW." This transmission was received by flight 191. The terminology used by the AR-1 controller contained no quantitative modifiers and did describe with reasonable accuracy the radar portrayal on which the advisory was based.

The Tower Cab.--At 1803:58, flight 191 established radio contact with the LCE controller, stating, "Tower, Delta one ninety one heavy, out here in the rain, feels good." The LCE controller testified that he did not report the presence of the rainstorm to flight 191 because the flight had reported that it was in the rain and was therefore as aware of the weather conditions as he was.

Two of the ATC personnel in the tower cab working the airport's east complex observed lightning before the accident. This type of information, when possessed by controllers, should be passed on to the weather observer, the TRACON, and to arriving and departing pilots. The air traffic control assistant saw lightning, but was unable to state the precise time she saw it. The control assistant said that the lightning occurred sometime between 1800 and the accident. The control assistant did not bring the sighting to the attention of the LCE controller.

The LCE controller also saw lightning between the time the Learjet landed and the time he saw flight 191 emerge from the rain shower. At 1805:44, the local controller asked the pilot of the Learjet to "expedite" his landing roll; therefore, the Learjet probably landed about 1805:14. At 1805:56, the local controller instructed flight 191 to "go around," so he saw the lightning sometime during that 42-second interval. Since lightning is a significant meteorological event and also indicates that the cell discharging the lightning has reached thunderstorm level, the local controller should have reported its occurrence. Had the LCE controller reported his sighting to flight 191, it probably would not have altered the outcome since the flight entered the microburst windfield about 1805:14.

Several air carrier flightcrews at DFW Airport saw lightning to the north of the airport. While it is not possible to fix the precise times of the sightings, the evidence indicates that these sightings preceded the accident by 2 to 5 minutes. One of these flightcrews also believed they saw a tornado; however, this sighting was just before the accident. None of the flightcrews reported these sightings to the tower.

The flightcrew of an air carrier flight which landed about 4 minutes before the accident saw lightning on either side of their airplane after passing inbound over the outer marker on their landing approach to runway 17L. After landing, this flightcrew stated that they observed a phenomenon which they described as a "waterspout." However, the flightcrew did not report either the waterspout or lightning to the tower after landing.

Had any of these flightcrews delivered a PIREP to the DFW Tower concerning these meteorological events, the TRACON and tower cab controllers would have been required by regulation to repeat the PIREP to all airplanes on their respective frequencies immediately. Some of these flightcrews were on the local control frequency when they observed these events. Had they reported their observations at any time after 1804, flight 191's flightcrew would have overheard the PIREP, and depending on how quickly it was reiterated, they would have also overheard the controller's required repetition of the PIREP. The Safety Board concludes that had the captain of flight 191 received PIREPs describing lightning near the airport and the sightings of a "tornado" and a "waterspout" north of the airport, he probably would have rejected the approach and maneuvered his airplane to avoid the rain shaft below the thunderstorm. Therefore, the Safety Board concludes that the failures to provide the captain with these PIREPS was causal to the accident.

The Safety Board also notes that comments from pilots, as well as the lack of adverse comments, affects the way controllers handle weather information. Not once before the accident did any pilot request to discontinue his approach, elect to hold elsewhere awaiting improvement of the weather, or provide any adverse comments to ATC personnel after landing. If pilots continue to accept instructions or routes which require weather penetrations, the controllers can only assume the route is acceptable. When flight 191 reported on initial contact with the LCE controller that it was in rain and that it "feels good," it was, in essence, a PIREP, but one without adverse comment. The transmission showed that the pilot was aware of the rain and that the rain was not creating any problems.

2.4 Operational Factors

The Safety Board's examination of the Delta windshear training program showed that while the curriculum discussed the necessity of avoiding windshears, it also recognized that in some instances a pilot might inadvertently encounter one. As a result, its simulator curriculum taught the procedure of using maximum thrust, increasing the airplane nose-up pitch attitude, and allowing airspeed to decrease to near stickshaker speed if necessary to avoid ground contact, and lowering the nose slightly if the stickshaker was actuated. Windshear training, as it existed at Delta before the accident, was in agreement with accepted industry standards. Although the captain's and first officer's training records did not show that they received this training, they probably received it during their LOFT and recurrent training periods. The captain's instructions to the first officer concerning the impending loss of indicated airspeed after they penetrated the microburst's windfield and his subsequent commands to apply full power tend to corroborate that he, at least, had received this training.

Windshear Avoidance.--The precise location and moment that a microburst will occur cannot be forecast. As of this date, a forecast technique has been developed that allows meteorologists to predict the type of day on which a microburst is likely; however, the technique does not permit the meteorologist to state what time and where the microburst will impact. Furthermore, this forecast technique only applies to the high plains dry microburst and may not apply to the moist, humid areas of the United States. Since the most violent windshear activity is associated with convective weather, and since microbursts are a product of convective activity, the best way to avoid the microburst type of shear is to avoid flying under or in close proximity to the convective type of clouds, i.e. cumulonimbus, towering cumulus, and in particular, thunderstorm.

The Delta Flight Operations Procedures Manual states that below 10,000 feet, thunderstorms are to be avoided by 5 miles. Furthermore, the Delta company publication Up Front published an article on microbursts which stated in part, "Microbursts occur from cell activity. Do not take off or land directly beneath a cell, whether it is contouring or not." Although the article contained a disclaimer, Delta's Systems Manager for Training stated that the article was not contrary to company policy and, in addition, Delta would not permit material contrary to the company's flight procedures and policies to be presented to its flightcrews in Up Front.

Airborne Weather Radar.--The evidence concerning the use of the airborne weather radar at close range was contradictory. At the public hearing and during a later deposition, testimony was offered that the airborne weather radar was not useful at low altitudes and in close proximity to a weather cell, whereas, with regard to the RDR-1F system which was on flight 191, the manufacturer's maintenance manual did not contain any cautionary language regarding the use of the set at close range with the minimum range setting.

At least three airplanes scanned the storm at very close range near the time of the accident. The radars used were the Bendix RDR-4A color radar, which unlike the RDR-1F contains a 20-nmi range setting. However, the RDR-1F will contour and the RDR-4A will display red at about the same level of reflectivity. All three of the airplane's radars painted the storm as an area of solid red with few or no transitional color areas. The captain of the flight behind flight 191 was able to view the storm on his radar when his airplane was at or approaching the outer marker.

At 1759:37, flight 191 was about 7 nmi northeast of the cell and was requested to turn right to 340°. Between 1751 and 1800, the cell had intensified from a VIP level 1 to VIP level 4, and flight 191's nose was pointed at the cell until 1759:37. Except for a period between 1755:53 and 1757:19 during which a portion of the checklist was being completed, the flightcrew was relatively free of in-cockpit duties. During this period the flightcrew would have been free to use the weather radar to scan the cell and to manipulate the antenna tilt to acquire the best possible radar picture. Since the storm cell had reached a VIP level 4 by 1800, the cell would have reached contouring levels of intensity for their radar sometime during this period. However, the CVR contains no conversation referring either to what was or was not displayed, difficulties involved with manipulating the radar antenna tilt, or the inadequacies of the radar in this area of flight. Since it is also possible that the flightcrew did try to use the radar but did not engage in any discussion over the results of the attempt, the Safety Board is unable to determine if the radar had been turned off, or whether the flightcrew tried to use it during the final moments of the descent and as the flight approached the outer marker. Furthermore because of the conflicting evidence, the Safety Board cannot determine the capability of the weather radar in a low-altitude, close-range weather situation.

Operational Decisions.--The Safety Board's investigation has documented the weather information which was either not transmitted to the flightcrew or, because of the time constraints involved in making the observation and transmitting the data was unavailable to the flightcrew. Regardless of the information which was not disseminated to the flightcrew, the primary issue facing the Safety Board was whether the information that was available to the flightcrew and the captain, either through their own observations or from ATC during the descent and approach to the DFW Airport, sufficient for them to assess the developing weather situation along the final approach to runway 17L and then make a proper decision either to continue the landing approach or to take alternate action. The Safety Board believes they did have sufficient information to make this assessment.

The forecasts provided on departure advised the flightcrew that the atmosphere around the DFW Airport was unstable and capable of producing an air mass thunderstorm. By 1756:28, after receiving an ATC "all aircraft" broadcast, the flightcrew knew that localized shower type of precipitation, precipitation that results from convective activity, was in progress north of the DFW Airport and that it was of sufficient intensity to impair in-flight visibility and to require that ILS approaches be made to runway 17L. The facts showed that within the next 4 minutes, the crew became aware that they would have to fly through the precipitation area to land, that the shower was still in place, and that its intensity had not decreased since ILS approach procedures were still required.

During the descent, the buildup causing the shower was visible to the flightcrew. Since the flight approached from the east and, when it was about 5 nmi northeast of the buildup, was vectored by ATC to an upwind leg, a downwind leg, and a base leg before being vectored to the final approach course, the flightcrew should have been able to get a good view of the storm cell and its dimension.

When flight 191 turned final the flightcrew heard the AR-1 controller's broadcast to all aircraft that the shower was just north of the airport and was affecting the surface winds, and 3 seconds later one of the flightcrew members said that the "stuff was moving in." Forty-nine seconds later the first officer reported that he saw lightning coming from a cloud or clouds "right ahead" of the airplane, and 42 seconds after that the rainfall intensified enough that it could be heard on the CVR. By this time the captain should have known that the rain was coming from a buildup or buildups over and directly in front of the airplane, that these were the buildups which produced the lightning that prompted the first officer's PIREP, and that the buildup or buildups contained a thunderstorm. The captain also had to know that the thunderstorm was between his airplane and the airport and, according to company policy, should be avoided.

Since the approach was continued, it would seem that the captain did not consider the observed lightning, when placed within the context of all the other available information, of sufficient importance to execute a missed approach. In an attempt to understand why the captain made the decision, which in retrospect was improper, the Safety Board examined the factors which affect how pilots make decisions. A NASA technical memorandum described this decisionmaking process as follows:

> . . . in order to accomplish any task, a pilot must first seek and acquire information from whatever sources are available. He must then make

some determination regarding the quantity, and the quality, of the information he has gathered. Previously gathered knowledge, contained in his memory, will influence the determination of whether he had enough information, of high enough quality, to allow him to proceed. Psychological or environmental stress can also influence his evaluation of the information.

Having determined that he has enough information, and that it is reasonably reliable, the pilot must then process these data in predetermined ways (again based on memory) in order to reach a wise decision from a limited number of alternatives. Before he finally accepts the decision he has made, however, he will make some judgment as to the acceptability of the candidate decision in terms of its potential impact upon the likelihood of successful mission completion. If the decision is finally accepted, the pilot selects the ways in which he will implement it, and then takes appropriate actions.

A large part of this process involves the pilot's judgment of probabilities; he is attempting to make wise decisions, often in the face of uncertainty. In addition, he must consider cost and safety tradeoffs, and there is good evidence that all of these factors do influence decision-making in the aviation system. 26/

In this case, conflicting information was available to the captain. The weather information, as provided by the controller and observed by him, showed a rapidly developing thunderstorm. The discussion in the cockpit showed that the crewmembers were aware that the rain was of sufficient intensity to "wash the airplane" and it was moving toward the airport. Finally, based on just what was visible, they knew they were going to penetrate an "opaque rain shaft" which had lightning associated with it.

The captain had to be aware of the company policy concerning thunderstorm avoidance. Indeed, given the prudent conduct he had exhibited earlier in the flight, the Safety Board believes that had this cell been positioned farther from the airport, providing him with more space to maneuver and still land, it was a cell he would have avoided. However the position of the storm did not allow him that luxury. Thus, given the company's stated thunderstorm avoidance policy, he would have had to reject the approach and hold till the storm moved off. Since he had adequate fuel to hold for about 20 minutes before leaving for his alternate, the airplane's fuel supply did not require him to fly the approach at this precise moment.

Upon landing at Dallas, the flightcrew was scheduled to fly to Orlando, Florida. Because the Orlando trip was scheduled to depart DFW Airport at 1957, a 20-minute hold would not have imperiled their availability for the flight. However, a diversion to their alternate would have, and this could have influenced the captain's appraisal of the weather between him and the airport.

Other factors could have influenced the captain's appraisal of the weather. There had been no report of LLWAS-detected windshears during the flight's decent. However, the controllers had begun reporting wind gusts and although the speed of the gusts was not excessive, the fact that they had just begun marked a change in the weather.

26/ A Method for the Study of Human Factors in Aircraft Operation, TM X-62, 472, National Aeronautics and Space Administration, September, 1975.

Flight 191 was one of a stream of airplanes landing at the airport, and all of these airplanes had landed without reporting difficulties or unusual conditions on the approach. The two airplanes just ahead of flight 191 had landed without reported difficulty. This fact could have led the captain to believe that, despite its appearance, the storm did not contain any dangerous weather or that the dangerous portion of the cell was still moving toward the approach course but had not, as yet, reached it.

When the lightning was reported and the heavy rain encountered, flight 191 was within 4 nmi of the end of runway 17L. Since there had been no reports that the weather had reached the airport, and, in fact, it had not, the airport was clear. Given his airspeed, he was within 2 minutes of landing and he might have decided that his exposure to the observed weather would be minimal.

All of these factors may have led the captain to misappraise the weather and to ignore one other factor, which he should have known intimately, especially given his experience and the fact that most of Delta's route structure lies in areas where severe convective storms occur often. Convective-type storm cells are volatile; therefore, a preceding airplane may encounter little if any weather but the following airplane can encounter a fully developed storm. The captain should have been well aware of the volatility of these storms and of the risk of basing a decision on the actions of a preceding captain.

The Safety Board believes that the captain had sufficient information to appraise the weather along the ILS localizer course to runway 17L. The Safety Board believes that the captain's misappraisal of the severity of the weather could have resulted from any, or a combination of, the factors cited above.

Although the Safety Board believes the accident could have been avoided had the procedures contained in the Delta thunderstorm avoidance policy been followed, the absence of more specific operational guidelines for avoiding thunderstorms in the terminal areas provided less than optimum guidance to the captain and flightcrew. The circumstances of this accident indicate that there is an apparent lack of appreciation on the part of some, and perhaps many, flightcrews of the need to avoid thunderstorms and to appraise the position and severity of the storms pessimistically and cautiously. The captain of flight 191 apparently was no exception. Consequently, the Safety Board believes that thunderstorm avoidance procedures should address each phase of an air carrier's operation and, in particular, the carriers should provide specific avoidance procedures for terminal area operations.

While it is the captain's responsibility to decide either to continue or discontinue a landing approach, the Safety Board believes that in this case, it was a flightcrew decision. Both the first and second officers were aware of the weather astride the final approach course and 1 minute elapsed between the time the first officer reported sighting lightning and the entry into the microburst windfield. Either the first or second officer had ample time to inform the captain that they believed that the approach should be discontinued. Given the fact that the captain was described as one who willingly accepted suggestions from flightcrew members, the Safety Board has no reason to believe that his demeanor would have influenced either man to delay or withhold suggestions to him relative to the safety of the airplane. Since these suggestions were not forthcoming, the Safety Board believes that neither officer saw any reason to suggest that the approach be discontinued and that they concurred with the captain's intent to continue. Therefore, the flightcrew was responsible for the decision.

The Safety Board has long advocated providing cockpit resource management training to captains and assertiveness training to first officers. Since Delta does not provide this type of training, formally, to its flightcrews, the Safety Board carefully examined the CVR transcript and the prescribed L-1011 operational procedures. While the Board's examination has shown that the suggestions cited above were not forthcoming, it also disclosed that there was a free and unrestricted transfer of information among the flightcrew members, that observations relating to the weather were made without apparent reservation, that the checklists were called for and completed promptly, and that there was no breakdown in flightcrew coordination procedures. Although in this instance the lack of formal cockpit resource management and assertiveness training was not causal to the accident, the Safety Board believes that this training is necessary to ensure the proper exchange of information among flightcrew members and should be provided by the air carrier companies.

Decisions During the Approach.--The analysis of the flight recorder data shows that, at 1805:05, about 45 seconds after the first officer's observation of lightning, the airplane began to encounter an increasing headwind component. The airplane was descending through about 875 feet AGL on the ILS glideslope at 150 KIAS (Vref + 13 knots). The onset of the increase was gradual, but between approximately 1805:12 and 1805:19 the headwind component increased more rapidly at a rate of about 2.7 knots/second. During this 7-second period, the airplane accelerated to about 173 KIAS, and the first officer retarded the throttles. By 1805:15, all three engines were either at, or very near, flight idle EPR. During the first part of this period, the first officer also had applied a gradual nose-down control correction. The pitch attitude decreased from about 4° nose-up to 1.3° nose-up and then began to increase as the first officer began to apply nose-up control corrections. At or shortly before 1805:19, the airplane encountered a strong downdraft. The vertical winds changed from a 10-fps updraft to a 20-fps downdraft. The first officer's response was to apply further nose-up control correction, and the pitch attitude increased to about 7° nose-up. At 1805:19, as the airplane entered heavy rain, the captain warned the first officer, "watch your speed," which was followed almost immediately by the more definitive comment, "you're gonna lose it all of a sudden, there it is." The airplane performance analysis shows this comment referred to a significant loss (44 knots) of indicated airspeed in 10 seconds as the airplane traversed the increasing headwind, followed by downdraft, and then by decreasing headwind windshear. Since the captain was familiar with this type of windshear from recurrent ground and simulator training and based on information provided in Delta's L-1011 POM, the Safety Board concludes that, although he may not have anticipated an encounter with a microburst, the captain was quick to recognize its manifestations. The Safety Board concludes also from the captain's commands to push the power up--"way up, way up, way up"--following the predicted loss of airspeed, that he was familiar with the actions needed to restabilize the airplane on the glideslope.

At 18:05:29, as the airplane was descending through about 650 feet AGL, the decreasing trend of the headwind reversed itself which, along with a high thrust condition, resulted in a rapid increase in airspeed from about 129 to 140 KIAS. As a result, at 18:05:31, thrust was reduced (from an engine pressure ratio of 1.47 to 1.33) to counter the rapidly increasing airspeed. The airplane momentarily stabilized on the glideslope despite airspeed fluctuations of +20 knots to -44 knots and downdrafts from 15 to 40 fps as it descended through the heavy rain. Consequently, the Safety Board concludes that the flightcrew probably believed that the airplane had penetrated the worst of the windshear, that the airplane would emerge shortly from the heavy rain, and that continuation of the approach was warranted. Also, it concludes that these beliefs may have been prompted by the flightcrew's windshear training and simulator experience in which they had successfully flown through microburst demonstrations that had incorporated the classic downburst outflow with its increasing headwind, downdraft, and decreasing headwind, and subsequent restabilization of the aircraft.

Based on his windshear training and L-1011 simulator experience with windshear encounters, the captain's decision to continue the approach was understandable following momentary stabilization of the airplane above 500 feet AGL at 1805:31. However, within the next several seconds, the flight encountered a second severe disturbance subsequently identified as the vortex ring consisting of large variations in wind components along all three axes of the airplane. Indicated airspeed decreased from 140 to 120 knots, the vertical wind reversed from a 40-fps downdraft to a 20-fps updraft, and a severe lateral gust struck the airplane. This gust resulted in a very rapid roll to the right, which required almost full lateral flight control authority to counter and to level the wings. Consequently, the airplane's angle of attack increased from 6° to approximately 23° degrees, and most likely increased more rapidly, and to a higher value, than recorded by the DFDR because of the rate-limited angle of attack sensors. The severe environment that flight 191 encountered during the 5 seconds after 1805:31 most likely prompted the captain to say, "Hang onto the (nonpertinent word)" at 1805:36. Also, at this time, the flightcrew probably first considered the execution of a missed approach, but they were likely too occupied with the immediate task of maintaining control of the airplane in the turbulence to audibly express these thoughts. However, engine thrust had been applied and the airplane momentarily rose slightly above the ILS glideslope. Six seconds after the captain's above comment, with engine thrust at or near maximum, the airplane began a rapid descent which was not arrested until ground contact 10 seconds later, at 1805:52. The Safety Board believes that the audible command TOGA issued by the captain 3 seconds after the glideslope departure, and 9 seconds after maximum thrust had been applied, may have been confirmation of the missed approach and an indication that he had switched the flight director from the approach/land mode to the TOGA mode.

The Safety Board is concerned that the present training within the industry for windshear encounters on the final approach seems to advocate the philosophy that the retrieval of the approach profile is the desired end result and not escape from the environment. For example, the landing windshear procedures in the Delta L-1011 POM advised the pilot "to be prepared to apply thrust immediately to maintain a minimum of Vref when encountering the shear and to be prepared for a prompt reduction of thrust once normal target speed and glide path is reestablished." The Safety Board believes that training should emphasize that in an environment wherein extreme pitch attitude changes and large applications of engine thrust are required to maintain altitude and minimum airspeeds, flightcrews should be taught that the only objective of the procedure is to escape and thereafter place the maximum distance between the ground and the airplane as soon as possible. In this regard, the Safety Board notes that the revision to the Delta windshear procedures issued after the accident provides Delta flightcrews with additional criteria to determine when the airplane's flight path control has become destabilized. The revised procedures advise the flightcrews to be prepared to execute a missed approach below 1,000 feet AGL if they encounter either "severe turbulence or indications of unstabilized flight path control."

Airplane Control During Microburst Penetration.--Delta and most major air carriers taught their flightcrews to trade airspeed for altitude if they inadvertently encountered low-altitude windshear. This technique was practiced in the simulators, including the L-1011 simulators, and flightcrews were taught to increase the airplane's pitch attitude and to add maximum thrust if necessary to control the airplane's flightpath. If necessary to avoid ground contact, the pitch attitude could be increased until the stickshaker activated and then decreased slightly to an attitude which would silence the stickshaker. Thereafter, the airplane's pitch attitude should be kept at an attitude just below that which would reactivate the stickshaker until the end of the windshear area was traversed.

The first officer was apparently able to apply the above techniques to keep the airplane on the ILS glideslope as it passed through and beyond the initial portion of the microburst. When the airplane descended into the vortex, the combination of an airspeed loss of 20 KIAS and a strong updraft most likely caused a momentary (1-second) activation of the stickshaker. The Safety Board believes that the first officer acted reflexively when the stickshaker activated to exert a 20- to 25-pound forward push on the control column. This control column force and the longitudinal stability of the airplane resulted in the airplane nosing over to a -8.5° pitch attitude, a rapid departure from the ILS glideslope, and a descent rate which approached 5,000 fpm for an instant.

The NASA analysis of alternate flight paths showed that ground impact might have been avoided had the pushover force not been applied. However, the Safety Board recognizes that the airplane was in an extremely turbulent environment, and because of the rapid reversals of the vertical winds, the airplane was subjected to rapid changes in angle of attack, longitudinal pitch forces, and fluctuations of indicated airspeeds. Consequently, under these circumstances, the ability of the first officer to apply an optimum or recommended pitch control technique would have been subjected to a severe test.

The flightcrew had applied maximum thrust shortly before the airplane departed rapidly from the glideslope, and the captain called for TOGA within 3 seconds of glideslope departure. When TOGA was engaged, the command bars presented a "fly-up" command, and the airplane pitched upward in response to the first officer's application of a substantial nose-up control correction. During this period, the vertical wind changed from a 40-fps downdraft to a 10-fps updraft. The reversal in wind component combined with a substantial nose-up pitch rate increased the angle of attack rapidly. At 1805:48, 3 seconds after TOGA was engaged, a +2.0 g vertical acceleration was recorded and the stickshaker probably again activated for about 1 second. At 1805:50, the airplane began to pitch down. During this time, the magnitude of the "fly-up" command presented by the command bars had decreased; however, they were still presenting a "fly-up" command when the airplane began to pitch down. The data contained in the performance analysis and the flight director study do not permit the Safety Board to conclude that the first officer was "flying the command bars" during the short time that the TOGA Mode was engaged. The data suggest that, in response to the stickshaker, the first officer ignored the command bars and applied nose-down control to silence the stickshaker. The data also show that when the stickshaker activated, the airplane's pitch attitude was 6° nose-up, the airspeed was about 150 KIAS, and the airplane was accelerating. Consequently, had the first officer been able to match the airplane's pitch attitude with the command bar position, the airplane might have cleared the ground. The shallow tire marks in the soft ground about 1 mile before the runway 17L threshold indicates a rather mild touchdown and additional evidence that the airplane's descent had almost been arrested. However, because of the uncertainties in the dynamic wind analysis, and in further recognition of the turbulent environment affecting the flightcrew, the Safety Board cannot conclude that other pilots would have been able to avoid ground contact. The Safety Board believes, however, that avoidance of ground contact could only have been assured positively if the missed approach had been executed when the captain perceived the first indications of a microburst windshear, when the airplane was between 700 and 800 feet AGL.

Regardless of the first officer's response to the command bars, the flight director's TOGA mode did not provide optimum pitch command guidance for penetrating windshears. In this instance, 1.25 Vs was about 131 KIAS and stickshaker activation speed was about 111 to 113 KIAS. The TOGA logic was designed to maintain 1.25 Vs and, therefore, would present pitch command guidance that would sacrifice altitude to maintain 131 KIAS, even though that airspeed was well above stickshaker activation airspeeds. The sacrifice of altitude to maintain airspeed is contrary to present windshear penetration doctrines and, in this instance, it sacrificed the climb performance which was available down to and at stickshaker speed. The Safety Board notes that other air carriers have cautioned against the use of the TOGA mode during takeoff and go-arounds during windshear encounters; however, the Delta L-1011 POM provided no guidance regarding the limitations of the flight director system TOGA mode under such circumstances.

In conclusion, at 1748, Cell "D" did not exist. Within the next 12 minutes, the cell was born, grew to a VIP level 4 weather echo, and its growth to a VIP level 4 weather echo occurred beyond the geographical confines of the DFW Airport's LLWAS. The Safety Board believes that the storm cell's rapid development made it virtually impossible for routine weather observation and reporting procedures to transmit an accurate and timely description of the cell to the air traffic controllers and, in turn, to flight 191.

The facts and circumstances of the accident also showed that the controllers in the DFW ATCT were not aware of the severity of the weather contained in Cell "D." The microburst touched the ground about 9,000 feet beyond the closest LLWAS sensor and its divergent winds did not place the LLWAS into alarm until after the accident. In addition, the DFW ATCT did not have available the type of radars which could depict either the intensity of the precipitation or the speed of movement of the air within Cell "D." Therefore, while the controllers were able to locate the cell on their ASR-7 radar, they were not able to describe to flight 191 the severity of the weather associated with the cell. The Safety Board will not speculate as to what effect this corroborative information would have had on the course of events, but with the additional information on which to base his decision, the captain may have decided to make alternate action. Therefore, the Safety Board concludes that the limitations in the airport weather surveillance that precluded the controllers from detecting the severity of the weather on the final approach contributed to the accident.

Although the Safety Board concluded that the airplane's powerplants had neither failed nor malfunctioned, the positions of the components of the engine reverser systems on the airplane's engines showed that the captain or first officer had selected reverse thrust at or immediately after the airplane first touched down. However, given the fact that the positions of the engine reverser components also indicated that forward thrust had been commanded on the No. 2 and No. 3 engines while reverse thrust was still commanded on the No. 1 engine, the Safety Board concludes that forward thrust was selected on all three engines either simultaneous with, or immediately after, the No. 1 engine separated from the airplane. The Safety Board cannot determine whether the selection of forward thrust was a deliberate flightcrew action or whether one of the pilots had his hand on the reverse thrust levers and his hand was driven forward by the impact forces. Regardless of how it occurred, given the time of the occurrence and the facts and circumstances of the impact and postimpact sequence, the Safety Board concludes that the selection and withdrawal of reverse thrust on the engines did not contribute either to the accident or to the severity of the impact.

2.5 Occupant Survival

Fire entered the left side of the mid-cabin between the time the No. 1 engine struck the automobile on State Highway 114 and the time that it struck the south water tank. The airplane's ground speed was over 200 knots when it struck the south water tank. The impact destroyed the forward and mid-cabin sections and simultaneously ignited a large fire which enveloped the airplane. The impact caused the rear cabin and empennage to separate from the remainder of the fuselage between seat rows 33 and 34 and this section came to rest on its left side over 1,000 feet beyond the water tank. The separation caused massive disruption of the rear cabin from row 33 aft to row 40.

The mid-cabin forward of the separation was destroyed by impact forces and fire. Only eight passengers who were seated between rows 21 and 33 survived. All survivors suffered blunt force trauma; seven of the eight sustained burns in addition to blunt force trauma.

Another four persons, including a flight attendant, seated between the separation and row 40 survived. These persons occupied seats in the area of the rear cabin which had been damaged heavily in addition to the massive disruption of surrounding cabin structure. The Safety Board considers the survival of the 12 persons seated forward of row 40 most fortuitous inasmuch as 7 of them were burned and all were seated in portions of the cabin that had been subjected to the high-impact forces which destroyed seats and surrounding structure. Based on these facts, the Safety Board concludes that the impact sequence was not survivable for persons seated forward of row 40.

Except for the destroyed missing left cabin wall, the rear cabin between rows 40 and 46 was relatively intact. The six persons in this section who were killed had been seated along the missing left cabin wall. The surviving 14 passengers and 2 flight attendants had occupied seats located predominately in the center and right side of the cabin. The Safety Board concludes that the impact sequence was survivable for persons seated aft of row 40 and who occupied the center and right row of seats.

Except for one flight attendant and three passengers, all of the survivors escaped unaided from the rear cabin. Although the survivors' escape was greatly hampered because the cabin was lying on its left side and because they were covered with fuel and had fuel in their eyes, their ability to escape was facilitated because there was little disruption of the seats and furnishings in the center and right side of the cabin, there was adequate illumination inside and outside the cabin, and there was no fire. Had fire occurred within the aft cabin area, either in-flight, before the separation occurred, or on the ground with the cabin section lying on its left side, there surely would have been few if any survivors.

The Safety Board also tried to determine whether the survival possibilities of flight 191's occupants would have been enhanced had the airplane not struck the water tanks. At the time of the accident, two large fully fueled cargo airplanes--a McDonnell Douglas DC-8 and DC-10--and a Boeing 747 tail maintenance stand were located on a service ramp south-southeast of the water tanks. Had flight 191 missed the water tanks, it could have either struck these two airplanes and the maintenance stand or continued along the ground. Had flight 191 struck the two airplanes and the maintenance stand, the impact sequence and ensuing fire would have been equally or even more catastrophic than it was. Had flight 191 avoided the water tanks and the service ramp, the survival possibilities for its passengers probably would have been equally as bad or worse than those which existed in the actual impact sequence. Flight 191 was traversing unpaved ground at a ground speed in excess of 200 knots, its nose landing gear had separated, it was on fire and the fire had penetrated into the passenger cabin, and it was already breaking up as a result of impacting the automobile and several highway light standards. There is little doubt that the airplane would have continued to break apart and exacerbate the existing fire as it continued across the airport surface. Given these two scenarios, the Safety Board believes that a catastrophic and probably unsurvivable environment would have ensued regardless of whether flight 191 struck the airplanes and maintenance stand on the service ramp or avoided the service ramp and continued along the airport surface.

With regard to the flight attendant jumpseats' damaged seatbelts and shoulder harnesses, the testing showed that, although they had been manufactured in 1982, the damage had decreased their tensile strength significantly. Despite the fact that there are no procedures or guidelines to aid airline maintenance and inspector personnel in determining at what point the condition of the belts and harnesses require replacement, the severe and obviously long-standing damage clearly indicated that they should have been replaced in accordance with accepted airline maintenance practices. The incorrect installation of the restraint systems on the R-4 and L-4 flight attendant jumpseats would not have affected their performance; however, the fact that these defects were not discovered during the airplane's various maintenance inspections leads the Safety Board to believe that the airline's inspection procedures were less than adequate.

Emergency Response.--The DFW Airport's DPS personnel responded quickly and efficiently and contributed significantly to saving the lives of a number of seriously injured victims. The Safety Board believes that much of the effectiveness of the emergency response was due to the immediate availability of the airport's paramedic and EMT personnel.

However, the Safety Board's investigation disclosed several problem areas which, under other accident circumstances, could affect adversely the medical treatment and survival of accident victims at the airport. Forty-five minutes was required to complete the notification of off-airport agencies whose assistance might have been needed for lifesaving activities. The Safety Board believes that this was an excessive amount of time and that the DFW Airport Emergency Plan's communications procedures should be improved to provide for more efficient and timely notification of the mutual aid agencies.

The Safety Board also believes that had more persons with serious injuries survived, the lack of coordination with area hospitals could have decreased the ability of these hospitals to treat properly the number of types of casualties involved. Therefore, the improvements to the emergency plan should include procedures to provide timely information to those hospitals selected to receive casualties. The National Fire Protection Association (NFPA) recently issued guidance material on this subject. Chapter 3, Section 6.5 of NFPA 424M, Manual for Airport/Community Planning states:

> The plan should designate a medical transportation officer whose responsibilities include:
>
> (a) Alerting hospitals and medical personnel of the emergency.
>
> (b) Directing transportation of casualties to hospitals.
>
> (c) Accounting for casualties by recording route of transportation, hospitals transported to, and casualty's name and extent of injuries.
>
> (d) Advising hospitals when casualties are en route.

(e) Maintaining contact with hospitals, medical transportation, the senior medical officer, on-scene command post and the command post.

The Safety Board believes that the guidance material cited above should serve as a guideline for plans and procedures to coordinate the transportation of casualties from the accident scene to selected hospitals.

Disaster Preparedness.--The Safety Board recognizes that communications and coordination problems are likely to occur during any large emergency response effort involving multiple jurisdictions; however, thorough planning, training, and periodic full-scale drills can reduce such problems appreciably. The Safety Board believes that periodic tests of the DFW Airport Emergency Plan's communications procedures would have disclosed that the required notifications of off-airport agencies could not be completed within a reasonable timeframe, and that the system for alerting off-airport ambulances and hospitals was incomplete. These discrepancies, once identified, could have been corrected. Therefore, the Safety Board has forwarded recommendations to the FAA urging that these exercises be developed and conducted.

At the time of this accident, 6 years had elapsed since the last full-scale exercise of the DFW Airport Emergency Plan. This interval was excessive and most probably contributed to the difficulties experienced by the DPS personnel with off-airport notification procedures and with procedures in the assembly area for off-airport units.

The Safety Board has long believed that full-scale tests of emergency plans and procedures should be conducted periodically at certificated airports. As a result of its study of airport certification and operations, 27/ the Safety Board recommended on April 16, 1984, that the FAA:

> Amend 14 CFR 139.55 to require a full-scale demonstration of certificated airport emergency plans and procedures at least once every 2 years, and to require annual validation of notification arrangements and coordination agreements with participating parties. (A-84-34)

On August 6, 1984, the FAA replied that it intended to revise 14 CFR Part 139 to require full-scale demonstration of emergency plans and procedures where practicable and that the required timing will be "variable from 2 to 4 years based on the air carrier activity level at each airport." On October 23, 1985, the FAA issued Notice of Proposed Rule Making (NPRM) No. 85-22 containing proposed amendments to 14 CFR Part 139; however, the NPRM did not contain requirements for periodic demonstrations of certificated airport emergency plans and procedures. The Safety Board now deems the FAA's response to the recommendation unsatisfactory and reiterates Safety Recommendation A-84-34, which has been classified as "Open—Unacceptable Action."

3. CONCLUSIONS

3.1 Findings

1. Between 1752 and 1800, the Cell "D" radar weather echo positioned off the north end of the DFW Airport intensified from a VIP level 1 to a VIP level 4.

27/ Safety Study--"Airport Certification and Operations" (NTSB/SS-84/02).

2. The absence of the CWSU meteorologist from his station between 1725 and 1810, and the failure of CWSU procedures to require the position to be monitored by a qualified person during his absence precluded detection of the intensification of the weather echo north of the DFW Airport.

3. During its final approach to runway 17L, flight 191 flew into a very strong weather echo (VIP level 4) located north of the field. The weather echo contained a thunderstorm with a heavy rainshower.

4. The thunderstorm produced an outflow containing a microburst. The microburst touched down just north of the DFW Airport. The center of the microburst was 12,000 feet (1.97 nmi) north of the approach end of runway 17L and about 1,000 feet west of the extended centerline of the runway and the ground track of flight 191.

5. The microburst diameter was 3.4 kilometers. The horizontal windshear across the microburst was at least 73 knots, and the maximum updraft and downdraft were 25 fps (4.8 knots) and 49 fps (29 knots), respectively.

6. There were six distinct reversals of vertical wind components along the southern side of the microburst. The presence of this type of wind flow showed that vortices had formed along the boundary between the descending air and the ambient environment.

7. Flight 191 penetrated the microburst and the vortex flow in the southern side of the microburst.

8. The first officer successfully transited the first part of the microburst encounter by rotating the airplane above a 15° nose-up pitch attitude and by increasing engine thrust to almost takeoff power.

9. About 1805:35, 17 seconds before initial impact, the airplane encountered rapid reversals in the lateral, horizontal, and vertical winds causing the stickshaker to activate. The first officer exerted a 20- to 25-pound push force on the control column in response to the stickshaker.

10. The flight director was placed in TOGA mode during the initiation of a missed approach 7 seconds before initial touchdown. The flight director's TOGA mode does not command the optimum pitch attitudes required to transit a low-altitude windshear. However, the Safety Board could not determine whether the first officer was following the pitch commands provided by the flight director's TOGA mode during the final 7 seconds of the flight.

11. The first officer exerted a 20- to 25-pound pull force on the control column in order to avoid ground contact. The stickshaker activated momentarily, and the first officer relaxed the pull force on the control column, which made ground contact inevitable.

12. Delta 191 touched down softly and almost avoided ground contact.

13. The ATC controller's speed adjustment procedures were not causal to the accident.

14. The 3 nmi separation standard was not maintained between flight 191 and the preceding Learjet. The loss of separation did not contribute to the accident.

15. The Feeder East and Arrival Radar-1 controllers provided flight 191 with all weather information that was available to them.

16. Several flightcrews saw lightning in the rain shower just north of the airport; however, they did not report what they saw to the ATC controllers.

17. The LCE controller observed lightning about or shortly after the time flight 191 entered the microburst windfield. Therefore, the failure of the LCE controller to report it to flight 191 was not a causal factor.

18. The flightcrew and the captain had sufficient information to assess the weather north of the approach end of runway 17L. The lightning observed and reported by the first officer was adequate, combined with the other data known to the flightcrew and captain, to determine that there was a thunderstorm between the airplane and the airport.

19. The north side of the cell formation containing the thunderstorm was not masked from flight 191 by any intervening clouds.

20. The captain's decision to continue beneath the thunderstorm did not comply with Delta's weather avoidance procedures; however, the avoidance procedures did not address specifically thunderstorm avoidance in the airport terminal area.

21. After penetrating the first part of the microburst, the engine thrust which had been increased was then reduced and at 550 feet AGL the airplane had restabilized momentarily on the glide slope. The captain evidently believed that they had successfully flown through the worst of the microburst windshear, and the approach was continued.

22. The company had not provided guidance to its flightcrews concerning specific limits on the excursions of airplane performance and control parameters during low-altitude windshear encounters that would dictate the execution of a missed approach.

23. Although the captain did not audibly express his decision to execute a missed approach until he called for the selection of the "TOGA" mode on the flight director 7 seconds before initial impact, maximum engine thrust had been applied before the airplane's rapid departure below the glideslope.

24. The accident was not survivable for persons seated forward of row 40 although 8 persons seated forward of the row survived. The accident was survivable for persons located aft of row 40 and seated in the center and right row of seats.

25. Despite notification and coordination difficulties, the emergency response of the DPS personnel and equipment to the accident scene was timely and effective and contributed significantly to saving the lives of a number of the survivors.

3.2 Probable Cause

The National Transportation Safety Board determines that the probable causes of the accident were the flightcrew's decision to initiate and continue the approach into a cumulonimbus cloud which they observed to contain visible lightning; the lack of specific guidelines, procedures, and training for avoiding and escaping from low-altitude windshear; and the lack of definitive, real-time windshear hazard information. This resulted in the aircraft's encounter at low altitude with a microburst-induced, severe windshear from a rapidly developing thunderstorm located on the final approach course.

4. RECOMMENDATIONS

4.1 Recommendations Addressing Low-Altitude Windshear and Weather

This section will discuss previous Safety Board activities and recommendations relevant to the low-altitude windshear hazard.

Since 1970, the Safety Board has identified low-altitude windshear as a cause or contributing factor in 18 accidents involving transport category airplanes. Eleven of these accidents were nonfatal, but the other 7 resulted in the loss of 575 lives. Six of the fatal accidents and at least eight of the nonfatal accidents occurred after the airplanes encountered the convective downburst or microburst winds associated with thunderstorms or heavy rainshowers.

The accidents attributed to convective windshear have occurred during landing approach, attempted go-around, and takeoff phases of flight. One fatal accident occurred during a landing when the airplane encountered a windshear caused by a feature of the surrounding terrain—the windshear was cited as a contributing factor. The other two accidents, both nonfatal, occurred after the airplanes passed through frontal system boundaries during the landing approach.

One of the frontal system windshear encounters involved an Iberian Airlines DC-10 with 167 persons aboard which struck the approach light piers and seawall embankment during an ILS approach at Boston Logan International Airport on December 17, 1973. 28/ The airplane was damaged substantially when the landing gear sheared off, and there were serious injuries during crew and passenger evacuation. It could have been a catastrophic accident.

The findings about windshear in this accident investigation first prompted the Safety Board to recommend that the FAA require that windshear be included in pilot training programs and that the development of windshear detection systems be expedited.

28/ Aircraft Accident Report—"Iberia Lineas Aereas de Espana (Iberian Airlines) McDonnell Douglas DC-10-30, EC CBN, Logan International Airport, Boston, Massachusetts, December 17, 1973" (NTSB/AAR-74/14).

The crash of an Eastern Air Lines B-727 at John F. Kennedy International Airport, Jamaica, New York, on June 24, 1975, killed 113 persons. 29/ That accident occurred when the airplane encountered on final approach the outflowing winds and downdraft associated with thunderstorms. The airplane experienced a rapid loss of airspeed and developed a high descent rate from which it did not recover. Following the investigation of the accident, the Safety Board issued 14 safety recommendations which addressed the development of both ground-based and airborne equipment for detecting windshear, the determination of operational limitations for various types of aircraft, the enhancement of airborne vertical guidance equipment, and reiterated the need for enhanced pilot training programs.

Acknowledging the serious hazard presented by windshear encounters, the FAA and other government and industry organizations began extensive research and development programs which were in general consonance with actions recommended by the Safety Board. The occurrence of three more air carrier accidents between 1975 and 1977 30/ which were attributed to encounters with windshear placed more emphasis on the research and development efforts. Several positive actions resulted: pilot training programs were enhanced to increase flightcrew awareness of the hazard; operational techniques were evaluated in simulation; and various technologies for both ground-based and airborne windshear detection and monitoring equipment were evaluated.

Unfortunately, tangible benefits from the research and development of the past 10 years have yet to be realized. The only operational windshear detection system thus far is the LLWAS, an anemometer array around the airport which will alert the tower controller to shifting ground-level winds. The limitations of the system were acknowledged from the beginning and it never has been regarded as other than an interim measure until more sophisticated equipment is developed.

The limitations of LLWAS as an operational decisionmaking aid to flightcrews were illustrated by the crash of a Pan American B-727 during takeoff from New Orleans Airport on July 9, 1982. 31/ Although the LLWAS indicated windshear in the vicinity of the airport, there were no means to relate the information to the hazard presented to a particular takeoff. Consequently, the flightcrew of the accident aircraft failed to perceive the danger; 153 persons died when the flight encountered a classic microburst at or immediately after the point of takeoff.

The Safety Board again recommended actions to be taken by the FAA, several of which addressed the need to improve the current technology for systems so they could be used effectively for flightcrew operational decisions. Other recommendations addressed the use of the wealth of information gained from the JAWS program at the Denver Stapleton Airport to improve the LLWAS system and procedures for its use, to evaluate the potential of other technologies such as the microwave doppler radar for

29/ Aircraft Accident Report—"Eastern Air Lines, Inc., Boeing 727-225, John F. Kennedy International Airport, Jamaica, New York, June 24, 1975" (NTSB/AAR-76/08).

30/ Aircraft Accident Reports—"Continental Air Lines, Inc., Boeing 727-224, N88777, Stapleton International Airport, Denver, Colorado, August 7, 1975" (NTSB/AAR-76/14); "Allegheny Airlines, Inc., Douglas DC-9, N994VJ, Philadelphia, Pennsylvania, June 23, 1976" (NTSB/AAR-78/02); and "Continental Air Lines, Inc., Boeing 727-224, N32725, Tucson, Arizona, June 3, 1977" (NTSB/AAR-78/09).

31/ Aircraft Accident Report—"Pan American World Airways, Inc., Clipper 759, Boeing 727-235, N4737, New Orleans International Airport, Kenner, Louisiana, July 9, 1982" (NTSB/AAR-83/02).

detecting windshear, to develop better methods to communicate usable information to controllers and pilots for timely and accurate decisionmaking, and to provide better information for pilot training.

Primarily in response to congressional pressure, the FAA contracted with the National Academy of Sciences for a study of the windshear hazard and measures for accident prevention. The Safety Board's staff supported the study by providing details of accident data and the rationale for the Board's safety recommendations. The committee's findings and recommendations issued in September 1983 were consistent with the Safety Board's views.

The Safety Board has issued a total of 36 Safety Recommendations to the FAA related to the aviation windshear hazard. The recommendations are cited verbatim along with a summary of the FAA responses and the Safety Board-assigned status in appendix H.

The most significant recommendations were issued following the accidents at Boston Logan on December 17, 1973, at John F. Kennedy on June 24, 1975, at Philadelphia on June 23, 1976, and at New Orleans on July 9, 1982. Specifically, these recommendations addressed the needs for:

Windshear forecasting to define better the conditions conducive to microburst development and to inform dispatchers and pilots when these conditions are present as well as when there is a windshear potential involving nonfrontal systems.

Improved communications between the weather service, air traffic controllers, and pilots to ensure that pilots are provided the most current forecasts and existing conditions for planning flights, landing approaches, and departures.

Improved real-time detection of windshear conditions by (1) use of the LLWAS to its maximum potential by ensuring optimum placement of the anemometer array and optimum software alarm logic, and (2) expeditious development and installation of microwave Doppler radar equipment at airports located in areas of high microburst risk.

Pilot training which stresses avoidance of windshear and discusses the meteorological conditions conducive to the development of windshears, particularly convective windshears.

Pilot training programs which (1) discuss the aerodynamic performance problems associated with windshear penetrations as well as simulations of windshear encounters during all low-altitude phases of flight, (2) stress the need for rapid recognition and response by using all of the airplane's performance capability, and (3) address the effect of an out-of-trim speed condition on the control forces needed to use the airplane's performance.

Development, certification, and installation of airborne equipment which can provide the pilot early warning of windshear encounters and optimize the logic of command guidance instruments to enhance the pilot's response to the encounter.

Cooperative efforts with the FAA and industry personnel in accident investigations and in followup of the Safety Board's recommendations spurred the initiation of several windshear research and development projects in the late 1970s. These have included:

Development and implementation of the LLWAS.

Development of windshear models which were distributed for use in engineering aircraft performance simulation as well as in pilot training applications.

Development of airborne instruments designed to enhance pilot response to inadvertent windshear encounter and the adoption of standards for such instrumentation.

Distribution of an AC describing the windshear hazard and preferable piloting procedures in the event of inadvertent encounters.

Evaluation of several technologies for the detection of a windshear including acoustical Doppler, light detection and ranging, infrared radiometry, and microwave Doppler radar. Of these, microwave Doppler radar appears to offer the highest potential for consistent detection within the existing state-of-the-art.

Comprehensive study of the microburst phenomena and the use of microwave Doppler radar in the JAWS.

As a result of these FAA activities, 24 of the Safety Board's recommendations have been classified as "Closed--Acceptable or Acceptable Alternate Action." These include those recommendations for additional research of the hazard and those for the development and issuance of windshear guidance material. The other 12 recommendations have been classified as "Open-Acceptable Action," pending further action by the FAA. These recommendations address the need for a more definitive and standardized flightcrew training program, the modification or enhancement of present terminal weather detection equipment, and the hardware implementation of new technology.

On April 14, 1986, the FAA circulated the draft of an Integrated Wind Shear Program Plan to interested government agencies and the aviation industry for review. This plan describes the FAA's ongoing efforts to:

- o Develop an authoritative flightcrew training program for airline training departments, including operational procedures, classroom curricula, written manuals, video presentations, and simulator exercises.
- o Develop improved sensors for the surface detection of low-altitude windshears, including an enhanced LLWAS, NEXRAD, and airport Terminal Doppler Weather Radar (TDWR).
- o Develop sensors for airborne detection of windshear, using microwave Doppler, laser, or infrared radiometer technology.

All of these programs are currently under contract for development, and working groups have been established to develop warning threshold criteria and standardized communication terminology.

The FAA program addresses nearly all of the actions proposed in the Safety Recommendations issued by the Safety Board since 1973 and includes the milestone schedules for the implementation of actions that have been proven to be technically feasible. However, the Safety Board is concerned that one most important—and difficult--problem is not being adequately addressed for the present and is not specifically addressed in the FAA's current programs: the communication of hazardous weather information available from ground sensors to the flightcrew in time for the information to be useful in go/no-go decisionmaking. Current procedures to relay NWS information through the ATC system are not and will never be adequate for dynamic weather conditions. However, actions can be taken to improve these procedures.

Specifically, the Safety Board believes that additional NWS information should be transmitted on ATIS broadcasts. Other critical meteorological information must also be made immediately available to the local controller. Therefore, the Safety Board advocates that the FAA assign a qualified person to each major terminal facility to perform this function. The person should be a meteorologist and should function as do meteorologists in the CWSUs of the ARTCCs.

Although the Safety Board supports the FAA's program plan to implement the much needed TDWR, it believes that a concurrent effort is needed to evaluate the existing radars with lesser, but certainly useful, capabilities for expedited use at busy terminals. With TDWR installation, these "lesser" radars would eventually be transferred to airports not receiving the TDWRs. Existing weather radars which provide reflectivity levels and turbulence—but not definitive wind—information could be used by a terminal weather coordinator to augment LLWAS for detection of heavy rain and possible windshear in the airport vicinity. Further, the FAA's new ATC radars (ASR-9) have weather channel capability.

Thus, as a result of this accident investigation and a review of the FAA's ongoing activities, the Safety Board issued the following additional recommendations to the FAA:

> Issue an Air Carrier Operations Bulletin to direct Principal Operations Inspectors to require air carriers operating under 14 CFR Part 121 to record in pilot training records the specific windshear simulator training administered to pilots during initial and recurrent training sessions. (Class II, Priority Action) (A-86-65)
>
> Issue an Air Carrier Operations Bulletin to direct Principal Operations Inspectors to review those sections of company operations manuals and training curricula pertaining to thunderstorm avoidance procedures to verify that flightcrews clearly understand the policy that no aircraft should attempt to land or take off if its flight path is through, under, or near (within a minimum specified distance) a thunderstorm. (Class II, Priority Action) (A-86-66)
>
> Issue an Air Carrier Operations Bulletin to direct Principal Operations Inspectors to require that company operations manuals and training curricula caution pilots not to use flight director systems during an inadvertent windshear encounter unless such systems incorporate windshear logic. (Class II, Priority Action) (A-86-67)
>
> Include a message on the Automatic Terminal Information Service broadcast whenever weather conditions conducive to thunderstorm or

microburst development exist in the terminal area or when such actual conditions have been observed or reported. (Class II, Priority Action) (A-86-68)

Amend Federal Aviation Administration Handbook 7210.3G, Facility Operation and Administration, to require the observation of lightning or existence of cumulonimbus and towering cumulus clouds as items to be included on Automatic Terminal Information Service broadcasts when that information has been included in the remarks section of official weather reports. (Class II, Priority Action) (A-86-69)

Require tower controllers to issue thunderstorm, microburst, and windshear reports when conditions differ from Automatic Terminal Information Service broadcast information and when actual pilot reports (PIREPS) have been received, and to solicit further PIREPS until such time that confirmation is received that the condition no longer exists. (Class II, Priority Action) (A-86-70)

Develop a position in major terminal facilities, to be staffed with National Weather Service meteorologists or Federal Aviation Administration personnel trained for meteorological observations, to be the focal point for weather information coordination during periods of convective weather activity that adversely affects aircraft and air traffic control system operations. (Class II, Priority Action) (A-86-71)

Require that all personnel engaged in weather coordinator duties attend the formal Weather Coordinator Training Course offered by the Federal Aviation Administration Academy, and expand that course to include training in the interpretation of weather echo intensity levels as depicted on remote weather radar displays. (Class II, Priority Action) (A-86-72)

Develop a thorough convective weather refresher course as part of recurring training for all personnel actively engaged in the control of air traffic. (Class II, Priority Action) (A-86-73)

Issue a General Notice to all en route and terminal facilities emphasizing the phraseology requirements for describing weather areas as stated in Federal Aviation Administration Handbook 7110.65D. (Class II, Priority Action) (A-86-74)

Conduct, during the current convective season, an operational test of currently available weather radar systems at selected airports and, based on the results of the evaluation, consider deployment of a system or systems to supplement data derived from the Low Level Wind Shear Alert System as an interim measure until deployment of advanced Doppler radar in terminal areas. (Class II, Priority Action) (A-86-75)

The Safety Board also issued the following recommendations jointly to the Federal Aviation Administration and the National Weather Service:

Develop procedures to require that Center Weather Service Units are attended constantly during operation so that information concerning hazardous weather conditions, such as thunderstorms, windshear, icing, and turbulence, either occurring or expected to occur, receives prompt, appropriate dissemination. (Class II, Priority Action) (A-86-76)

Develop procedures to require the Center Weather Service Unit meteorologist to disseminate information on rapidly developing hazardous weather conditions, such as thunderstorms and low-altitude windshear, to Federal Aviation Administration Terminal Radar Approach Control and/or tower facilities immediately upon detection of the conditions. (Class II, Priority Action) (A-86-77)

Expedite the implementation of equipment to upgrade all Center Weather Service Units to the state of the technology in data acquisition and display capability. (Class II, Priority Action) (A-86-78)

The Safety Board also issued the following recommendations to the National Oceanic and Atmospheric Administration:

Require that pertinent information and formal training programs derived from microburst and convective storm research be provided in a timely manner to operational meteorologists. (Class II, Priority Action) (A-86-79)

Require that all offices that have a weather radar display or displays and an aviation weather warning responsibility to airports have those airports clearly located on a useable map on each weather radar display. (Class II, Priority Action) (A-86-80)

Develop definitive aviation weather warning criteria based on radar weather echo intensities and the proximities of radar weather echos to airport approach and departure corridors, and implement a means to communicate this information immediately to Federal Aviation Administration Terminal Radar Approach Control and tower facilities. (Class II, Priority Action) (A-86-81)

4.2 Other Recommendations

Two safety problems not related to the low-altitude windshear hazard were evident in the investigation of this accident. Both of these problems are serious in that they can directly affect the survival of persons involved in an aircraft accident.

The first problem involved the restraint systems at the airplane's flight attendant jumpseats. The shoulder harnesses and seatbelts were badly worn and were, in some cases, improperly installed. To correct the deficiencies, the Safety Board recommended that the Federal Aviation Administration:

Issue an Advisory Circular with guidance on the limits of wear and damage to restraint system webbing material that would necessitate the replacement of worn or damaged webbing. (Class II, Priority Action) (A-86-82)

Review, and require improvements as necessary in, Delta Air Lines quality control program regarding inspection and replacement of restraint systems. (Class II, Priority Action) (A-86-83)

> Issue a maintenance alert bulletin that cites the problems of the flight attendant restraint system discovered following the Delta L-1011 accident at Dallas/Fort Worth International Airport, Texas, on August 2, 1985, and require Principal Maintenance Inspectors to emphasize to air carriers the requirements and guidance for periodic inspections of flight attendant restraint systems for worn and damaged webbing, improper installation, and worn shoulder harness guides. (Class II, Priority Action) (A-86-84)

> Issue an Airworthiness Directive to correct the design deficiency of Heath Techna jumpseats (Part No. MPD 241100) that permit the seatbelt webbing to chafe against the seatpan retraction spring. (Class II, Priority Action) (A-86-85)

> Perform a Directed Safety Inspection of flight attendant restraint systems on air carrier aircraft to determine design deficiencies that cause damage to webbing materials, and establish a program as needed to replace worn or damaged webbing and correct design deficiencies. (Class II, Priority Action) (A-86-86)

The second problem involved the communications and coordination with off-airport medical units during the implementation of the Dallas/Fort Worth Airport Emergency Plan after the accident. To correct the problem, the Safety Board sent a letter to the executive director of the airport which recommended that the airport board:

> Revise its disaster response notification procedures to provide for timely and effective notification of mutual-aid agencies whose assistance is needed. (Class II, Priority Action) (A-86-87)

> Revise its procedures for coordinating with area hospitals during mass casualty disasters to provide the hospitals with timely information regarding estimated numbers of victims, injury categories, destinations, and arrival times. (Class II, Priority Action (A-86-88)

> Conduct full-scale demonstrations of the Dallas/Fort Worth Airport Emergency Plan and Procedures every 2 years. (Class II, Priority Action) (A-86-89)

In addition, the Safety Board believes that full-scale tests of emergency plans and procedures should be conducted periodically at certificated airports. As a result of its study of airport certification and operations, the Safety Board recommended that the Federal Aviation Administration:

> Amend 14 CFR 139.55 to require a full-scale demonstration of certificated airport emergency plans and procedures at least once every 2 years, and to require annual validation of notification arrangements and coordination agreements with participating parties. (A-84-34)

On August 6, 1984, the FAA replied that it intended to revise 14 CFR Part 139 to require full-scale demonstration of emergency plans and procedures where practicable and that the required timing will be "variable from 2 to 4 years based on the air carrier activity level at each airport." On October 23, 1985, the FAA issued NPRM No. 85-22 containing proposed amendments to 14 CFR Part 139; however, the NPRM did not contain requirements for periodic demonstrations of certificated airport emergency plans and procedures. The Safety Board now deems the FAA's response to the recommendation unsatisfactory and reiterates Safety Recommendation A-84-34, which has been classified as "Open--Unacceptable Action."

The Safety Board also recommended that the Federal Aviation Administration:

> Develop guidelines for use by Airport Certification Inspectors to determine the timeliness and effectiveness of emergency notification procedures at certificated airports. (Class II, Priority Action) (A-86-90)

> Require Airport Certification Inspectors to conduct communications tests in accordance with Federal Aviation Administration guidelines for emergency plan notification procedures of mutual-aid agencies as part of the annual airport certification inspection and to evaluate the timeliness and effectiveness of those notification procedures. (Class II, Priority Action) (A-86-91)

The Safety Board also recommended that the American Association of Airport Executives and the Airport Operators Council International:

> Advise its members of the circumstances of the emergency response to the accident at Dallas/Fort Worth International Airport, Texas, on August 2, 1985, and urge them to reevaluate their own plans and procedures to identify any similar strengths and weaknesses. (Class II, Priority Action) (A-86-92)

> Urge its members who operate 14 CFR Part 139 certificated airports to conduct full-scale demonstrations of airport emergency plans and procedures every 2 years. (Class II, Priority Action) (A-86-93)

The Safety Board also recommended that the National Fire Protection Association:

> Advise its Technical Committee on Aircraft Rescue and Firefighting of the circumstances of the emergency response to the accident at Dallas/Fort Worth International Airport, Texas, on August 2, 1985. (Class II, Priority Action) (A-86-94)

ICAO Note.— Section 1.17, Figures 1 to 4 and Appendices A to H were not reproduced.

ICAO Ref.: 149/85

No. 6

Boeing 747 SR-100, JA8119, accident at Gunma Prefecture, Japan, on 12 August 1985. Report released by the Aircraft Accident Investigation Commission, Japan

1. Synopsis

JA8119, a Boeing 747 SR-100 of Japan Air Lines Co., Ltd, (JAL) during a flight from Tokyo to Osaka scheduled as flight 123 on August 12,1985, experienced an emergency at about 1825 when approaching east coast of Southern Izu Peninsula, and after a continued flight of about 30 minutes the aircraft crashed among mountains in Ueno Village, Tano Gun, Gunma Prefecture at about 1856.

On board the aircraft were 509 passengers (including 12 infants) and a crew of 15; 524 persons in total, of which 520 persons (505 passengers and 15 crew-members) were killed, and 4 passengers seriously injured.

The aircraft was destroyed and fire occurred.

2. Factual Information

2.1 History of the Flight

On August 12,1985, the day of the accident, JA8119, a Boeing 747SR-100 of JAL was operated prior to this flight as scheduled flights 503, 504, 363, and 366 by crew other than the crew of the accident flight, except for the flight engineer (on duty on board flights 363 and 366).

The aircraft, as flight 366 (Fukuoka—Tokyo), landed at Tokyo International Airport (TIA) at 1712, parked at Spot 18 at 1717, and thereafter was inspected in preparation for operation as flight 123 (Tokyo—Osaka).

The flight plan which was submitted to TIA Office of Tokyo Regional Civil Aviation Bureau, reads; IFR, cruising speed 467 knots (TAS), Flight Level (FL) 240, destination Osaka International Airport(OIA), via Mihara Sagara, Seaperch, W27, Kushimoto VORTAC, V55, Shinoda VOR/DME, and Osaka NDB, estimated flight hours 54 minutes up to Osaka NDB with fuel on board 3 hours and 15 minutes expressed in flight duration hour.

The aircraft, with the captain seated at the right-hand seat and the copilot on the left for the purpose of training the copilot for position as captain, started taxiing from Spot 18 at 1804, and took off from Runway 15L at 1812. (hereafter, refer to Attached Figure)

The aircraft requested Tokyo Area Control Center (Tokyo ACC), about 1816:55 while climbing to FL240, for a direct route to Seaperch(A non-compulsory reporting point at 253° , 74 NM from Oshima) from present position, and the request was approved at 1818:33.

At 1824:35 just before the aircraft reached FL240, heading towards Seaperch and approaching east coast of South Izu Peninsula, the aircraft was brought into an abnormal situation which greatly affected continuation of the flight. At the same time, a loud noise like a "boom" was heard, immediately followed by an utterance of "squawk 77" (meaning emergency code number 7700 of ATC transponder)by both the captain and the copilot. Then, at 1825:21 the captain requested Tokyo ACC clearance to descend to and maintain FL220, and to return to TIA on account of occurrence of such an abnormal situation. At 1825:40 the aircraft requested radar vector to Oshima. To this request, Tokyo ACC inquired which was desired, right or left turn for change in heading for TIA, and received the response from the pilot that he intended to make a right turn. Tokyo ACC, accordingly, issued instructions to fly on a magnetic heading of 090° after making a right turn for radar vector to Oshima, which was acknowledged by the aircraft at 1825:52.
Thereafter, the aircraft deviated from the course somewhat to the right near the middle of Southern Izu Peninsula, crossed the Peninsula heading WNW to cross over Suruga Bay. At about this time, unusual phugoid and dutch roll motions began, and these phenomena with large or small amplitude continued until the crash. At 1827:02 Tokyo ACC confirmed the declaration of an emergency and then asked "What is the nature of the emergency ?", but received no response from the aircraft. At 1828:31 Tokyo ACC instructed again the aircraft to "take a magnetic heading of 090° for radar vector to Oshima", but the response "now uncontrollable" was received from the aircraft at 1828:35.

The aircraft traversed Suruga Bay, passed over north of Yaizu City, Shizuoka Prefecture at about 1830, and then changed course to the right for a northbound flight at about 1831, about which time Tokyo ACC asked the aircraft "Can you descend ? ", to which the pilot responded "Now descending" at 1831:07, and then reported his altitude as FL240 in response to the subsequent inquiry on current altitude. To a question made by Tokyo ACC at 1831:14 "Your present position is 72 NM from Nagoya Airport. Can you land at Nagoya ? ", the aircraft answered "Request return to TIA". At 1831:26 Tokyo ACC suggested the use of Japanese to communicate thereafter, which was acknowledged by the aircraft.

At about 1835, the aircraft turned to the right at a point about 35 KM W of Mt.Fuji for an eastward flight, and about 1838 turned the heading to the left at a point about 7 KM NNW of Mt.Fuji into a north-eastward flight, and at about 1841 the aircraft started a descent from about FL210 over the vicinity of Otsuki City, Yamanashi Prefecture to about FL170 changing the heading about 360° to the right in about 3 minutes. Thereafter the aircraft continued flight descending rapidly eastward, transmitting "aircraft uncontrollable" at 1845:46, then turned left

towards NE. At 1847:07 the aircraft requested radar vector to TIA, to which Tokyo ACC instructed the aircraft to "maintain heading of 90° . TIA's active runway 22", which was acknowledged by the aircraft. Then, in response to an inquiry "Is the aircraft controllable?" made by Tokyo ACC at 1847:17, "uncontrollable" was answered. At about 1848 the aircraft turned to the left at an altitude of about 7,000 feet over the vicinity of Oku-Tama Town, Nishi-Tama Gun, Tokyo and flew WNW gradually climbing, and after reaching about 13,000 feet at about 1853 it started again a descent, and transmitted "uncontrollable" at 1853:31. At 1854:19, the aircraft switched over communications to Tokyo Approach Control (Tokyo APC) at an altitude of 11,000 feet by an instruction of Tokyo ACC. At 1854:25 the aircraft requested its position, to which Tokyo APC gave "55 NM NW of TIA and 25 NM W of Kumagaya", which was acknowledged by the aircraft at 1854:55. Then, at 1855:05 Tokyo APC transmitted "Both TIA and Yokota are available", to which acknowledgement was made by the aircraft. After this, there was no response from the aircraft to calls of Tokyo APC as well as Yokota Approach Control.
According to statements of eye-witnesses (4 persons) at points 3 to 4 KM SSW of the crash point, "The aircraft flew in buzzing from Oku-Tama area located to the ESE at quite a low altitude and slow speed, slightly nose-up. The aircraft passed overhead, and made an abrupt right turn short of Mt.Sanpei (elevation 1,700 m) situated to the NW and flew toward Mt. Mikuni (elevation 1,828 m) located to ENE. Then, about the time the aircraft would have passed Mt.Mikuni, the aircraft suddenly plunged into a dive banking to the left to NW direction, and went out of sight behind the mountain. Thereafter, smoke and flashing lights were seen emanating from behind the mountain."

The aircraft struck several trees on the ridge (elevation about 1,530 m) located about 1.4 km NNW of Mt.Mikuni, then contacted the ridge (elevation 1,610 m) located 520 m WNW of the previous ridge, and finally crashed on a ridge located further about 570 m NW of the second ridge. The crash point was on the ridge (elevation 1,565 m, 35° 59′ 54″ N, 138° 41′ 49″ E) about 2.5 km NNW of Mt.Mikuni located on boundaries of Gunma, Nagano and Saitama Prefectures.

The estimated time of the crash is at approximately 1856.

2.2 Injuries to Persons

Injuries	Crew	Passengers	Others
Fatal	15	505	0
Serious	0	4	0
Minor/None	0	0	

2.4 Damage to Aircraft

2.4.1 Extent of Damage

The aircraft was destroyed.

4. Conclusions

4.1 Summary of Analysis

4.1.1 General Matters

4.1.1.1 The flight crew were properly qualified and had passed the established medical examination.

4.1.1.2 It is acknowledged that the then existent meteorological conditions were not directly relevant to the occurrence of the abnormal situation.

4.1.1.3 Functions and operational conditions of aids to navigation and ATC unit are acknowledged to have been normal.

4.1.1.4 The aircraft was certificated and maintained according to approved procedures.

4.1.2 Flight of the Aircraft up to the Occurrence of the Abnormal Situation

4.1.2.1 On August 12, 1985, the aircraft took off from TIA 1812 as flight 123, subsequent to preceding four scheduled flights on the day. There were neither reports of abnormalities nor flight discrepancies regarded as relevant to this accident in the preceding four flights as well as in the inspection and maintenance conducted between them (including the pre-flight check as flight 123).

4.1.2.2 At 1824:35, about 12 minutes after take-off, an abnormal situation occurred so as to exert serious influence on continuation of the flight, up to which time the flight is considered to have been normal.

4.1.3 Repairs for Damage caused by the Accident at Osaka International Airport

【On June 2, 1978, JA8119, during a landing roll at OIA struck its aft fuselage on the runway and the airframe was substantially damaged. The aircraft was ferried to TIA after provisional repairs made by JAL at OIA from June 7 to 14, 1978. The regular repairs were carried out by an AOG (Aircraft on Ground) repair team of the Boeing Company (TBC) at TIA between June 17 and July 11, 1978. 】

4.1.3.1 It is acknowledged to have been proper that the repair work related to structures of the aircraft was accomplished by the Boeing Company for JAL by the contract, because the aircraft was manufactured by the company, etc.

4.1.3.2 The repair plan of the aircraft agreed on between JAL and the Boeing Company is considered to have been proper in general.

4.1.3.3 When the lower half of the aft pressure bulkhead deformed by the accident was removed and was being replaced by the new one in accordance with the repair plan, it was found that there were locations where the edge margin around the rivet holes at the splice (L18 splice) of the upper and the lower webs of the aft pressure bulkhead was less than the value specified in the structure repair manual. This is considered to have been caused by somewhat insufficient concern against deformation of the aft fuselage in the repair work of the aft pressure bulkhead.

4.1.3.4 For the above, the corrective measure to make a splice joint by inserting a splice plate between webs of the upper half and the lower half of the aft pressure bulkhead, which is considered as proper, was planned. But, during the repair, improper work was conducted in which different from the intended corrective measure, one splice plate narrower than drawing requirements, and one filler were applied instead of one splice plate.

4.1.3.5 In inspections during and after the repair work, the afore-mentioned improper part of the work could not be found.

4.1.3.6 It is considered that the method of management for the work including the inspection of working process was in part insufficient.

4.1.3.7 It is estimated that during this rework, part of L18 splice which should have been spliced by two-row rivets became spliced by one-row rivets, with the result that the strength of this part decreased to about 70% of the strength to be obtained by the original splice method. From this, it is estimated that these portions were brought under a condition susceptible to occurrence of fatigue cracks.

From the above, it is considered that the aft pressure bulkhead of the aircraft had been lacking in fail-safe capability since this time.

4.1.4 Fail-safe Capability of Boeing 747 Aircraft

The fail-safe design of Boeing 747 is in accordance with standards on airworthiness of transport category airplanes of the FAA, which was in effect at that time.

Provisions on airworthiness set forth minimum requirements for capability which aircraft should provide, but they would not guarantee the airworthiness under conditions caused in a very rare case, nor caused by improper repair work.

It is conceivable that the reason why ruptures propagated as a chain reaction in this accident is that prior concern had not reached as far as to the prevention of such situation from occurring, although the fail-safe design of the aircraft in the development stage, and inspection and maintenance methods which incorporated service experience were proper to meet the provisions concerned.

4.1.5 Operation and Maintenance of the Aircraft after the Osaka Accident

4.1.5.1 The flight hours and the number of flights (number of landings) of the aircraft after the repairs for the accident at Osaka International Airport in June, 1978 up to this accident were 16,196 hours and 12,319, respectively.

4.1.5.2 During this period, in L18 splice of the aft pressure bulkhead, a number of fatigue cracks were caused and propagating mainly at one-row rivet connection portions.

4.1.5.3 It is considered that there were neither abnormalities nor flight discrepancies deemed to be related to this accident in flights during this period.

4.1.5.4 During this period C maintenance (a maintenance every 3,000 hours) was conducted 6 times, at which time visual inspection was made, but fatigue cracks which had been existent at the rivet connected portions of L18 splice were not found.

The inspection method of the aft pressure bulkhead in the time of C maintenance might have been a proper method, because it was unconceivable at the time the said C maintenance was conducted that a number of fatigue cracks came into existence in this portion, provided the bulkhead was manufactured normally and repair work was done properly.

It is considered that the inspection method was not proper in part, in view of the fact that such fatigue cracks as to cause the aft pressure bulkhead to rupture were not found, although they resulted from the improper repair work.

4.1.6 Outlines of the Abnormal Situation

The conditions of the abnormal situation in which the accident aircraft was brought are considered as follows:

4.1.6.1 At about 1824:35, when the aircraft climbed to about FL240, the pressure differential between the pressurized cabin and outside atmosphere became about 8.66 psi, it is estimated that bay 2 whose residue strength had reduced remarkably by propagating fatigue cracks was fractured, being unable to bear the pressure differential, and with this as a trigger L18 splice went into a total fracture at a stroke.

It is considered that the fracture propagated thereafter upward in the central portion of the bulkhead along the collector ring, and furthermore progressed upward along R6 and L2 stiffeners, and meanwhile in the outer edge portion of the bulkhead, the fracture propagated upward along Y chord.

4.1.6.2 As a result of such progress of the fracture, part of the web of the upper half of the aft pressure bulkhead was blown up aft by the air pressure of the passenger cabin to make an opening. The area of the opening is estimated as of an order of 2－3 square meters.

4.1.6.3 It is estimated that the inner pressure of the tail section increased by the pressurized air of the cabin flowed in through the opening of the aft pressure bulkhead, thereby the APU firewall was broken, and part of the tail section structure including the APU located aft of the wall was destroyed and separated.

4.1.6.4 It is considered that the destruction of the vertical fin was initiated immediately after, or almost simultaneously with the destruction of APU fire wall. It is estimated that part of the pressurized air of the cabin which flowed into the tail section rushed into the vertical fin through the opening in the lower portion of the aft torque box of the vertical fin, thereby increasing the inner pressure of the vertical fin, and the fixture between the stringer and the rib chord in the upper portion of the aft torque box was destroyed at first. It is estimated that thereafter destruction of the internal structures of the aft torque box and peel-off of the skin were caused, followed by separation of the upper half of the forward torque box, most of the aft torque box, the fin tip cover, etc.

4.1.6.5 It is estimated that the damage to the aft torque box of the vertical fin caused separation of the rudder, and four systems of hydraulic pressure line for the rudder control system were all fractured.

4.1.6.6 It is estimated that such destruction of the aircraft progressed within a period of as short as a few seconds.

4.1.6.7 It is estimated that the pressure in the cabin including the cockpit reduced to the atomospheric pressure within a few seconds due to the opening of the aft pressure bulkhead.

4.1.6.8 It is estimated that by the afore-mentioned destruction of the airframe, control functions of the rudder and elevator and the trim function of the horizontal stabilizer were lost immediately after the abnormal situation occurred. It is also estimated that control functions of the aileron and the spoiler, and operational functions of the flaps and the gear by hydraulic pressure were lost within 1.0—1.5 minutes after the abnormal situation occurred.

4.1.6.9 It is estimated that due to loss of most of control functions and extreme deterioration of the lateral and directional stability, the maintenance of attitude and heading, and control of climb, descent, turn, and so forth became extremly difficult.

4.1.6.10 It is estimated that severe phugoid motion and dutch roll motion, of which control were difficult, were caused to the aircraft.

4.1.6.11 It is considered that the aircraft was not able to continue a stable flight and any flight as intended by the captain was difficult, and that a safe landing or landing on the water was next to impossible.

4.1.7 Flight of the Aircraft after the Occurrence of the Abnormal Situation and Responsive Actions Taken by the Flight Crew

4.1.7.1 It is estimated that the flight crew immediately became aware of occurrence of some kind of abnormality, but they remained ever since unaware of details of the damage such as rupture of the vertical fin and separation of the rudder.

4.1.7.2 It is estimated that soon after the occurrence of the abnormal situation, the flight crew became cognizant of depressurization of the airframe, and nonetheless the flight crew did not put the oxygen mask up to the last. The reason, however, could not be clarified.

4.1.7.3 After the occurrence of the abnormal situation, the aircraft, without making an emergency descent, continued flight for about 18 minutes at an altitude of more than 20,000 feet, making phugoid motion and dutch roll motion. It is conceivable that the reason the emergency descent was not made during this period regardless of the intention expressed by the flight crew to make an emergency descent was that they were devoted to the control action to stabilize the flight attitude. However, the definite reason could not be determined.

It is conceivable also that the flight crew suffered from hypoxic hypoxia during this period, whereby their capability of dealing with intelligent work as well as their behavior were deteriorated to some extent.

4.1.7.4 Thereafter, a gear-down operation was conducted, the aircraft entered into a descent and the phugoid motion subsided. When the aircraft descended to an altitude of about 7,000 feet, the flight crew noticed the aircraft was approaching mountains. As soon as they raised engine power immediately, the aircraft would have been brought into an unstable flight condition again, being accompanied by phugoid motion and dutch roll motion.

4.1.7.5 After the occurrence of the abnormal situation, the flight crew not only fell into an abnormal situation which was out of the scope of the education and training they received or the knowledge and experience they had, but also was unable to comprehend fully the substance of the abnormal situation, and furthermore they were brought into a severe environment of being subjected to severe motion and depressurization of the aircraft. For these reasons, it is conceivable that they were concentrated on the operation to stabilize the flight while being not able to make a pertinent judgement on how to cope with the situation.

4.1.8 Crash of the Aircraft

4.1.8.1 It is estimated that the aircraft which was in the unstable flight condition hit "the single larch tree" and "the U-shaped ditch" both short of the crash point, with the result that the remaining portion of the vertical fin and the horizontal fin as well as the engines, etc., were separated from the airframe at this time.

4.1.8.2 It is estimated that thereafter the aircraft collided against the crash point with an attitude of the nose and the right wing both down. The time of crash is estimated as approximately 1856:30 hours based on records of the DFDR and seismometer, etc.

4.1.8.3 By the severe shock at the time of crash the fore fuselage and the right wing were broken into small fragments and dispersed. The aft fuselage is estimated to have been separated by the shock at the time of crash, and fallen into the 3rd branch of Sugeno Dale passing over the ridge line. The other parts were dispersed in a wide area involving the crash point.

4.1.8.4 Fuel supposed to have been dispersed from the fuel tank flamed up, and the wreckage dispersed in the vicinity of the heliport which had been constructed after the accident for rescue purpose was burnt down.

4.1.9 Injuries to Passengers and Crew

4.1.9.1 It is considered that passengers and crewmembers in the fore and mid fuselage were all instantaneously killed by the shock estimated as much as hundreds of G as well as the total destruction of structures of the fore and mid fuselage at the time of crash.

4.1.9.2 Out of passengers and cabin attendants who were in the aft fuselage, those seated on forward seating are considered to have been killed almost instantaneously due to a possible strong shock in excess of 100 G's at the time of crash.

The shock persons on the aft seating were subjected to was also of an order of tens of G, and by this shock most of them are considered to have undergone fatal injuries. Moreover, the possibility would be considered high that since the flooring, seating, galley, etc were all destroyed and dispersed by the shock at the time of crash, they were killed enlarging the extent of injuries by bruise and oppression resulting from collision with such broken pieces.

4.1.9.3 Four persons survived this accident, but they were all seriously injured. All of them were seated at the rear portion of the aft fuselage and are considered to have been subjected to tens of G, but they were able to escape death miraculously. The conceivable reason would be that their seating attitude, way to fasten the belt, status of damage to the seat, status of substances sorrounding their body, etc., at the time of collision chanced to help buffer the impact, and that they were less subjected to collision with dispersed internal substances of the fuselage.

4.2 Cause

It is estimated that this accident was caused by deterioration of flying quality and loss of primary flight control functions due to rupture of the aft pressure bulkhead of the aircraft, and the subsequent ruptures of a part of the fuselage tail, vertical fin and hydraulical flight control systems.

The reason why the aft pressure bulkhead was ruptured in flight is estimated to be that the strength of the said bulkhead was reduced due to fatigue cracks propagating at the spliced portion of the bulkhead's webs to the extent that it became unable to endure the cabin pressure in flight at that time.

The initiation and propagation of the fatigue cracks are attributable to the improper repairs of the said bulkhead conducted in 1978, and it is estimated that the fatigue cracks having not be found in the later maintenance inspection is contributive to their propagation leading to the rupture of the said bulkhead.

5. Referential Matters

5.1 Actions and counter-measures taken up to May 31, 1987 by governmental organizations, aircraft manufacturers, and aircraft operators concerned, in reference to this accident are as follows:

5.1.1 National Transportation Safety Board (NTSB), USA made the following safety recommendations to Federal Aviation Administration (FAA), USA:

a) Design change on the empennage (Safety Recommendation A-85-133, Dec.5,1985)

Measures should be taken so that the empennage section of Boeing 747 and 767 will be protected against catastrophic failure in the event that a significant pressure buildup occurs in the normally unpressurized empennage.

b) Modification of the design of the hydraulic systems (Safety Recommendation A-85-134, Dec.5, 1985)

Design mofification should be made so that the integrity of all four hydraulic systems will not be impaired in the event that a significant pressure buildup occurs in the normally unpressurized empennage.

c) Reevaluation of the fail-safe validity of the domed aft pressure bulkhead (Safety Recommendation A-85-135, Dec.5, 1985)

Reevaluation should be made of the design of the aft pressure bulkhead of Boeing 747 and 767, and test be made to confirm their fail-safe validity.

d) Evaluation of procedures to repair the aft pressure bulkhead (Safety Recommendation A-85-136, Dec.5, 1985)

The current repair procedures of Boeing 747 and 767 aft pressure bulkheads should be evaluated to ensure that the repairs do not affect the fail-safe concept.

e) Revision of the inspection program for the aft pressure bulkhead (Safety Recommendation A-85-137, Dec.5, 1985)

In reference to the aft pressure bulkhead, an inspection program beyond the usual visual inspection should be established to detect the extent of possible multiple site fatigue cracking.

f) Evaluation of the fail-safe criteria of the domed aft pressure bulkhead (Safety Recommendation A-85-138, Dec.13, 1985)

Confirmation should be made on whether the fail-safe criteria have been satisfactorily evaluated for all domed aft pressure bulkheads of transport category airplanes.

g) Evaluation of repair procedures of the domed aft pressure bulkhead (Safety Recommendation A−85−139, Dec.13, 1985)

Procedures to repair the domed aft pressure bulkhead of all airplanes which incorporate the domed aft pressure bulkhead should be evaluated to assure that the affected repairs do not derogate the fail-safe concept of the bulkhead.

h) Issuance of a maintenance alert bulletin to persons responsible for the engineering approval of repairs (Safety Recommendation A−85−140, Dec.13, 1985)

A maintenance alert bulletin should be issued to persons responsible for the engineering approval of repairs to emphasize that the approval adequately consider the possibility of influence on ultimate failure modes or other fail-safe design criteria.

5.1.2 FAA directed US operators of the Boeing 747 and TBC to make the following modifications, inspections, etc.:

a) Vertical fin access cover installation (Airworthiness Directive AD86−08−02, April 4, 1986)

To install, within 6 months, a structural cover for the opening within the empennage which provides access to the vertical fin, to prevent destruction of the empennage structure due to a significant pressure buildup in the empennage. (A−85−133 related)

b) Reevaluation of the fail-safe validity of the domed aft pressure bulkhead

To request TBC to conduct a reevaluation of the design and tests concerning the fail-safe validity of the aft pressure bulkheads of Boeing 747 and 767. (A−85−135 related)

c) Evaluation of the repair procedures for the domed aft pressure bulkhead (Airworthiness Directive AD−85−22−12, Oct.25, 1985)

To request the operators to check on whether repairs of the aft pressure bulkhead of Boeing 747 have been carried out and to report the results to TBC.

No problems were found from the FAA's review on the results of reevaluation of the repair manuals of the aft pressure bulkhead of Boeing 707, 737, 747 and 767 issued by TBC. (A−85−136 related)

d) Review of the fail-safe criteria of the domed aft pressure bulkhead

FAA's TACD (Transport Airplane Certification Directorate) formed a team with the major aircraft manufacturers to study on NTSB's safety recommendations, and they are making a review of large aircraft exceeding 75,000 pounds taxi weight. Through the review, modifications of and additions to inspection procedures were brought into SID(AC91－51).

Reevaluation of the damage tolerance design is also under way. (A－85－138 related)

e) Evaluation of the repair procedures of the domed aft pressure bulkhead

FAA requested the large transport airplane manufacturers to review the repair criteria for the domed aft pressure bulkhead by a letter dated Dec.12, 1985. (A－85－139 related)

f) Issuance of a memorandum to the engineering staff

A memorandum concerning repairs of important major structures of the aircraft was issued to the engineering staff belonging to each ACO (Aircraft Certification Office) (A－85－140 related)

g) Modification of the hydraulic systems

FAA initiated, with TBC in September 1985, a study on modifications necessary to prevent loss of functions of the hydraulic systems following major structural failure of Boeing 747. This work is still under progress, but indications are that functions of the elevator, ailerons, and spoilers could be secured by installing a fuse before No.4 hydraulic system where the hydraulic lines enter the vertical stabilizer. TBC has issued a service bulletin which provides for installation of the fuse on No.4 hydraulic system, and the SB is planned to become an FAA directive. (A－85－134 related)

5.1.3 TBC issued the following SB's and at the same time conducted design modifications, tests, etc. on new production airplanes:

a) Vertical fin access cover installation (SB747－53A－2264, Nov.25, 1985)

TBC requested installation on airplanes in current use of the cover for the opening which provides access to the vertical fin. The installation on new airplanes was made from line number 626 (delivered Dec. 11, 1985). (A－85－133 related)

b) Modification of the hydraulic systems (SB747－29－2063, Dec.23, 1986)

TBC requested installation on airplanes in current use of the fuse in No.4 hydraulic systems upstream of the vertical stabilizer. The installation of the fuse on No.4 hydraulic system of new production airplanes was initiated at line number 663 (delivered Dec.23,1986).

The rerouting of the hydraulic line between BS1480 and 2460 will be incorporated in production starting with line number 696, which will roll out of the factory in January, 1988. A SB which provides for rerouting of the hydraulic line will not be issued due to technical complexity unless requested by an operator through the Master Change process. (A−85−134 related)

c) Reevaluation of fail-safe validity of the aft pressure bulkhead of Boeing 747 and 767

The fatigue test and damage tolerance test of the aft pressure bulkhead on the current design model as well as on the improved model were completed in March 1986 and in July 1986, respectively. (A−85−135 and −138 related)

d) Evaluation of repair procedures of the aft pressure bulkhead

Boeing sent a telegram to the operators requesting them to check whether repairs have been carried out, and to report details of the repairs conducted. (A−85−136 and AD85−22−12 related)

e) Development of the reinforced aft pressure bulkhead

The reinforced aft pressure bulkhead was installed from line number 672 delivered in February, 1987. The modification added two tear straps, a cover plate to the center of the bulkhead, and doublers to the both sides of the bulkhead around the APU cutout. (A−85−135 related)

f) Revision on the inspection program of the aft pressure bulkhead (SB747−53−2275, March 26, 1987)

TBC requested the visual inspection from the aft side at 1,000 flight-cycle intervals (freighters) or at 2,000 flight-cycle intervals (passenger airplanes); and after 20,000 flight-cycles, the detailed inspection by high-precision eddy current, ultrasonic wave and X rays at 2,000 flight-cycle intervals (freighters) or at 4,000 flight-cycle intervals (passenger airplanes).

As to 747SR, TBC requested the visual inspection at 2,400 flight-cycle intervals;and after 24,000 flight-cycles,the detailed inspection by eddy current, etc. at 4,800 flight-cycle intervals. (A−85−137 related)

5.1.4 Civil Aviation Bureau (JCAB), Ministry of Transport, Japan took the following actions for the safety operation of Boeing 747 and for the improvement of the search and rescue system for aircraft:

a) *Instructions to conduct overall inspection of the vertical* stabilizer and the rudder (Airworthiness Directive TCD−2483−85, August 15, 1985)

b) *Instructions to conduct overall inspection of the aft part* structure of the pressurized cabin (Airworthiness Directive TCD−2483−1−85, August 17, 1985)

c) Request was made to the airlines operating Boeing 747 in Japan to report results of repair of the aft pressure bulkhead to both TBC and JCAB to reevaluate the repair procedure. (JCAB Document Ku-Ken 747, Septemper 4, 1985)

d) Enforcement of an entry for inspection into JAL's Maintenance Department, and recommendation of service improvements based thereon for safety operation (September 5, 1985)

1) to conduct overall inspection on Boeing 747s whose number of pressurized-flight times has reached the order of 18,000.

2) to review the inspection items of C maintenance and others, and at the same time to improve work cards used in the inspection of airframe structures, for the reinforcement of airframe structure inspection of Boeing 747.

3) to set up a long-range monitor program of airframe structures damaged by an accident or others.

4) to review the sampling inspection procedures of airframe structures of Boeing 747, and at the same time to improve the technical evaluation procedures of the sampling inspection results.

Furthermore, to promote the development of preventive measures against the reoccurrence of major failures.

5) to ensure the thorough implementation of instructions from the maintenance department to the engineering planning department.

6) to reinforce the inspection and maintenance system of airframe structures as well as the all-round safety promotion system.

e) Notification to FAA of the inspection results of the pressurized cabin structures of JAL's Boeing 747SR's conducted pursuant to the service improvement recommendation, for FAA's further improvement actions to ensure the operation safety of the aircraft. (November 5/December 10, 1985)

f) Instructions to install a structural cover for the opening within the empennage which provides access to the vertical fin for the purpose of preventing the rupture of the fin structures due to flow-in of the pressurized air to the empennage aft of the pressure bulkhead. (Airworthiness Directive TCD-2611-86, May 7, 1986, A-85-133 related)

g) Instructions to incorporate SID items into the maintenance regulations as a measure to cope with the aging change of Boeing 747SR (Airworthiness Directive TCD-2636-86, October 13, 1986)

h) Up to Summer of 1986, the improvement of facilities of the TIA Office where the Search and Rescue Center is located and the communications network among organizations concerned was completed, and the necessary staff was increased. Furthermore, on August 7, 1986, a joint training was carried out by JCAB and organizations concerned.

5.1.5 JAL has effected or is planning the following improvement actions, counter-measures, etc.:

a) Design modification of the vertical fin (Airworthiness Directive TCD2611-86, AD86-08-02 and A-85-133 related)

On all Boeing 747's in current use the cover was installed to the opening which provides access to the vertical fin up to December 31, 1985. On JA8169 and the aircraft thereafter the cover is installed in their production.

b) Modification of the Hydraulic Systems

The installation of the fuse to the hydraulic systems on 4 aircraft in current use was completed by the end of May, 1987, and on the other aircraft in current use will be completed by the end of March, 1988. On JA8178 and the aircraft thereafter its installation is made at the production time. (A-85-134 related)

c) Evaluation of repair procedures of the domed aft pressure bulkhead

Inspection on all aircraft in current use was made as to whether repairs were conducted and to what extent the work was carried out, and their results were reported to both TBC and JCAB. (A-85-136 and 139, AD85-22-12, the TBC's Telegram, and JCAB Document Ku-Ken 747 related)

d) Revision of the inspection program of the aft pressure bulkhead

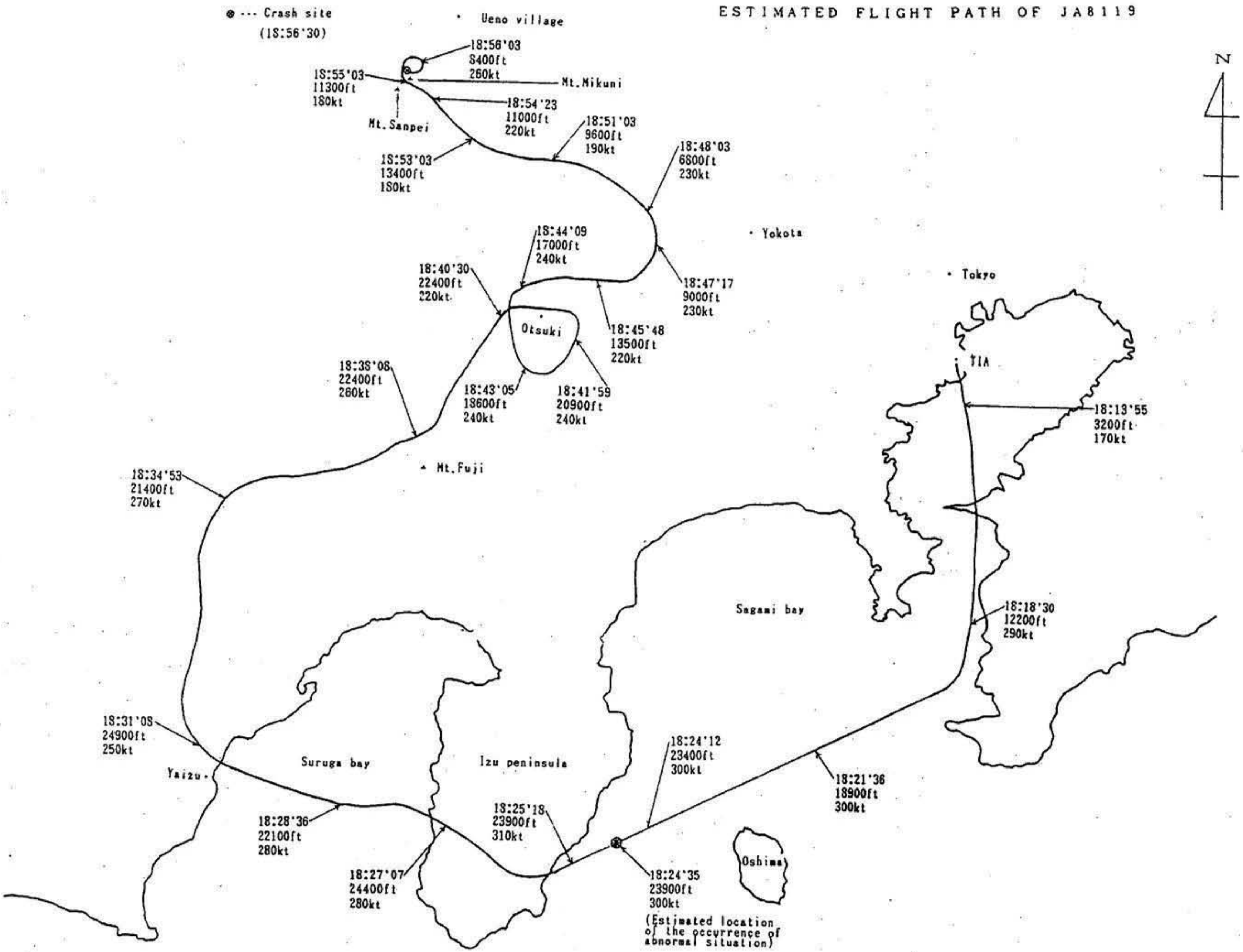
The eddy current inspections were implemented on six aircraft in the overall inspection of Boeing 747SR. (No cracks have been found) (A-85-137 Rescue related)

RECOMMENDATIONS

1. In case where large-scale repairs such as modifications of principal structural elements of an aircraft are carried out at a place other than the factory where the said aircraft was manufactured, for recovery from or repair of damage caused by aircraft accident, as much guidance as possible should be provided to the repair agency engaged in the repair work so that the planning and management of the repairs are conducted with special care as individual condition requires.

2. In case where large-scale repairs such as modifications of principal structural elements of an aircraft are carried out for recovery from or repair of damage caused by aircraft accident, as much guidance as possible should be provided to aircraft operator so that special instruction items, if necessary, are established for the portion concerned and continuous monitor is maintained.

ESTIMATED FLIGHT PATH OF JA8119



3. In this accident, ruptures of the fuselage tail, vertical fin, and hydraulical flight control systems were caused as a chain reaction by flowout of the pressurized air due to rupture of aft pressure bulkhead. To prevent the recurrence of such situation,a study should be initiated on the addition to the airworthiness standards of the provisions concerning the fail-safe capability of peripheral structures, functional systems etc, against rupture of pressurized structural components such as the aft pressure bulkhead on a large aircraft.

PROPOSALS

1. A study be made on measures to improve the ability of crews to respond to emergencies or abnormal conditions.

It is considered that the crew may not be able to grasp the situation sufficiently or they cannot make a judgement on how they should cope with the situation under the condition of specific emergency or abnormality, or under the condition of simultaneous occurrence of multiple emergencies or abnormalities, as in the case of this JA8119 accident.

It is necessary to study measures to improve the ability of the crew to cope with such cases.

2. A study should be made with respect to cracks detectability of visual inspection for the improvement of aircraft maintenance engineering.

In most cases, cracks caused on aircraft structures have been detected by visual inspection. However, no sufficient reference is presently available on the problem to determine to what extent the visual inspection is effective in detecting cracks.

It is necessary to study measures to improve aircraft maintenance engineering by collection and analysis of data on crack detectability by visual inspection on transport category airplanes in current use in our country.

ICAO Note.— This report was excerpted and abridged from the Final Report by the Aircraft Accident Investigation Commission, Japan.

ICAO Ref.: 147/85

No. 7

McDonnell Douglas DC-9-14, N100ME, accident at Milwaukee, United States, on 6 September 1985. Report No. NTSB/AAR-87/01 released by the National Transportation Safety Board, United States

SYNOPSIS

At 1521 c.d.t. on September 6, 1985, Midwest Express Airlines, Inc., Flight 105, a McDonnell-Douglas DC-9-14 airplane, crashed into an open field at the edge of a wooded area about 1,680 feet southwest of the departure end of runway 19R shortly after taking off from General Billy Mitchell Field, Milwaukee, Wisconsin. The weather was clear with visibility 10 miles. During the initial climb, about 450 feet above ground level (a.g.l.), there was a loud noise and a loss of power associated with an uncontained failure of the 9th to 10th stage high pressure compressor spacer of the right engine. Flight 105 continued to climb to about 700 feet a.g.l. and then rolled to the right until the wings were observed in a near vertical, approximately right 90° banked turn. During the roll, the airplane entered an accelerated stall, control was lost, and the airplane crashed. The aircraft was destroyed by impact forces and postcrash fire. The pilot, the first officer, both flight attendants, and all 27 passengers were fatally injured.

The National Transportation Safety Board determines that the probable cause of the accident was the flightcrew's improper use of flight controls in response to the catastrophic failure of the right engine during a critical phase of flight, which led to an accelerated stall and loss of control of the airplane. Contributing to the loss of control was a lack of crew coordination in response to the emergency. The right engine failed from the rupture of the 9th to 10th stage removable sleeve spacer in the high pressure compressor because of the spacer's vulnerability to cracks.

1. FACTUAL INFORMATION

1.1 History of the Flight

Midwest Express Airlines (Midwest Express) Flight 206, a McDonnell Douglas DC-9-14 airplane with United States registry N100ME, arrived at General Billy Mitchell Field, Milwaukee, Wisconsin, at 1315 c.d.t. 1/ on September 6, 1985. The flightcrew that was later to take flight 105 began their duty day as the crew on the continuation of flight 206 to Madison, Wisconsin. The oncoming crew was advised that no discrepancies had been noted during the initial preflight inspection of the aircraft that morning, and that no discrepancies were noted following a subsequent walkaround inspection at an intermediate stop. The airplane reportedly was "running fine" with only minor discrepancies that were not related to powerplant or flight control systems. The oncoming flightcrew reported no additional discrepancies during the continuation of flight 206, which departed Milwaukee at 1336 and arrived in Madison at 1355.

At Madison, N100ME was designated as flight 105; the crew did not change. The flight was scheduled to proceed to Atlanta, Georgia, with an intermediate stop in Milwaukee. Flight 105 departed Madison at 1425 and arrived at Milwaukee, on time and without incident, at 1441.

About 1449, the first officer of flight 105 contacted Milwaukee Tower to request an instrument flight rule (IFR) clearance to Atlanta. The clearance was received and read back by the first officer at 1450. At 1453, the captain contacted the Midwest Express dispatch facility in Appleton, Wisconsin, and received a briefing regarding his route of flight to Atlanta. The weather package applicable to the route of flight was forwarded to the captain via teleprinter. The Atlanta forecast included a 1,000-foot ceiling, visibility—2 miles, thunderstorms and rain showers. An alternate destination was planned in the event the flight could not land in Atlanta. Contingency fuel was added for possible en route diversions around the thunderstorms. The total dispatch fuel was 19,500 pounds. A loading schedule was forwarded to the flightcrew for verification and completion. The completed loading schedule indicated that the flight would be conducted within the applicable weight and balance limitations. The takeoff weight was approximately 77,122 pounds, the recommended stabilizer trim setting was 2.2 units nose-up, and the center of gravity was 29 percent mean aerodynamic chord. No hazardous material was manifested aboard the airplane.

The captain signed the dispatch release, which listed the previously noted minor discrepancies. He did not report any other mechanical irregularities or discrepancies. At 1512, the Before Engine Start Checklist was read and accomplished in accordance with Midwest Express operating procedures. Engine start was commenced at 1514. The After Start Checklist was accomplished about 1515, although the first officer did not report that the checklist was completed, as directed by the Midwest Express Crew Operating Manual (COM). The first officer requested clearance to taxi to runway 19R for departure; his request was approved at 1516:31. A Midwest Express service agent, who walked around the airplane to ensure all doors and panels were closed, reported that everything looked normal before the airplane departed the gate. Another agent reported that there were no fluid leaks after engine start.

1/ All times herein are central daylight, based upon the 24-hour clock.

About 1517:50, the Taxi Checklist was completed in accordance with the COM, and the engine pressure ratio (EPR) and airspeed reference 2/ bugs were set to 1.91 and 133 knots, respectively. (The referenced indications were correct for the departure conditions applicable to flight 105.) The Safety Board determined that the correct takeoff speeds for a 20° flap takeoff were: takeoff decision speed (V1)-123 knots indicated airspeed (KIAS), rotation speed (VR)-127 KIAS, and takeoff safety speed (V2)-133 KIAS. At the conclusion of the Taxi Checklist, the captain advised the first officer "Standard briefing . . ." 3/

At 1519:15, the first officer reported to the tower local controller, "Milwaukee, Midex 4/ 105, ready on 19R." Flight 105 was cleared to "position and hold" on runway 19R. The captain called for the Before Takeoff Checklist, which was completed in accordance with the COM at 1519:39. The crew did not mention any aircraft discrepancies during the preparation for departure. Flight 105 was cleared for takeoff at 1520:28; the first officer acknowledged the clearance. The captain operated the flight controls, and the first officer handled radio communications and other copilot responsibilities during the takeoff.

The Midwest Express DC-9 Flight Operations Manual required the use of standard noise abatement takeoff procedures during all line operations, unless precluded by safety considerations or special noise abatement procedures. (See appendix C.) At the time flight 105 departed, noise abatement procedures were in effect. Midwest Express also utilized "reduced thrust" takeoff procedures (at the captain's discretion) to extend engine life. The applicable EPR reduction associated with this procedure was from 1.91 to 1.90. Review of the recorded cockpit communications confirmed that the flightcrew was complying with the reduced thrust and standard noise abatement takeoff procedures.

At 1521:26.4, when the airplane was about 450 feet above the runway, there was a loud noise 5/ and a noticeable decrease in engine sound. The captain then remarked "What the # was that?" 6/ The first officer did not respond. At 1521:29, the local controller transmitted, "Midex 105, turn left heading 175." The local controller later testified that at the time of his transmission he observed smoke and flame emanating from the right airplane engine. At 1521:29.5, the captain asked the first officer, "What do we got here, Bill?" The first officer did not respond to the captain but advised the local controller, "Midex 105, roger, we've got an emergency here." Two seconds later, the captain said, "Here"; again there was no response. There were no further communications from the flight. Neither pilot made the call outs for "Max Power" or "Ignition Override-Check Fuel System," which were part of the Midwest Express "Engine Failure after V1" emergency procedure.

About 100 witnesses saw flight 105 depart runway 19R. Most of the witnesses reported that the takeoff appeared normal until the airplane reached an altitude of about

2/ Set to takeoff safety speed (V2) per Midwest Express procedures.
3/ Standard briefing, as defined by the Midwest Express chief pilot, is a phrase which indicates it is a standard day and normal procedures are to be utilized. The chief pilot said that discussion of the eventualities and responsibilities of takeoff emergencies were not required to be discussed before each takeoff. Standard briefings are routinely used when pilots are familiar with one another and departure conditions are routine.
4/ Midwest Express callsign.
5/ The loud noise was described in the CVR transcript as a "clunk" sound.
6/ The # symbol was used in the CVR transcript to describe a nonpertinent word which was not transcribed.

300 feet above ground level (a.g.l.). Liftoff reportedly occurred between the midfield taxiway and the intersection of runways 19R and 25L. Many witnesses reported that they saw smoke and/or flames coming from the right engine when the airplane was about 300 feet a.g.l. and that they heard one or more loud "bangs, similar to a shotgun report," which attracted their attention to the Midwest Express airplane. None of the witnesses described smoke or flames coming from any part of the airplane other than the right engine. None of the witnesses reported seeing parts falling from the aircraft in flight. They said flight 105 continued to climb briefly, apparently maintaining runway heading for a few seconds. Twenty witnesses said the airplane yawed and porpoised and/or that the wings rocked briefly, following the right engine failure. Several witnesses said that the nose then came downward to a near-level attitude; some of the witnesses said the airplane also appeared to have decelerated near the apex of its climb. The witnesses indicated that the airplane then rolled abruptly to a steep right bank, which increased to at least 90°. Witness accounts of the airplane maneuvers during its descent to the ground varied greatly. Most witnesses said that the airplane made 1 to 1 1/2 rotations in a nose-low spin in a right-hand direction. The airplane crashed into rolling terrain about 1680 feet southwest of the departure end of runway 19R.

The crash occurred at 1521:41, during daylight hours, in visual meteorological conditions, at 42° 55' 38" North latitude and 087° 54' 06" West longitude. All 31 occupants of the airplane were fatally injured.

1.2 Injuries to Persons

Injuries	Crew	Passengers 7/	Others	Total
Fatal	4	27	0	31
Serious	0	0	0	0
Minor/None	0	0	0	0
Totals	4	27	0	31

1.3 Damage to Aircraft

The airplane was destroyed by impact forces, explosion, and postcrash fire.

1.4 Other Damage

The impact and postcrash fire caused damage to low lying vegetation, trees, and a fence within a wildlife preserve.

1.5 Personnel Information

Both pilots met all Federal Aviation Administration (FAA) requirements applicable to their respective crew positions. (See appendix B.) Both pilots had received upgrade training, which led to Midwest Express DC-9 captain qualifications.

The captain, 31, was employed by Midwest Express as a DC-9-14 first officer on February 3, 1984. He upgraded to captain on February 7, 1985. At the time of his upgrade, he had accumulated 4,600 flight-hours, including 600 hours as first officer in the DC-9-14. He held an airline transport pilot certificate, which was issued on April 18, 1984, and a DC-9 type rating, which was issued on February 7, 1985. Company

7/ One nonrevenue passenger, who was authorized to use the cockpit jumpseat and was seated in the cabin, is included in the figures representing passenger injuries.

records indicated that, at the time of the accident, he had 5,100 hours total flight experience, including 1,100 hours in the DC-9-14 and 500 hours as captain. All of his turbojet experience was in the DC-9. Before his employment with Midwest Express, the captain was employed as a corporate pilot flying the Beech 90 turboprop Kingair. He had logged 2,900 hours in the Kingair, including 800 hours as pilot-in-command. According to Midwest Express, he had 104 hours total instrument pilot experience when hired.

The first officer, 37, was employed by Midwest Express on February 3, 1984, and received a DC-9 type-rating on February 15, 1984. At that time, he had accumulated 4,100 flight-hours, including about 500 hours as first officer in the DC-9-14. He had obtained the DC-9-14 pilot experience as an employee of K-C Aviation, Midwest Express' parent corporation. Company records indicated that, at the time of the accident, the first officer had 5,197 hours total flight experience, including 1,640 hours in the DC-9-14, and 1,140 hours as a DC-9-14 captain. The first officer had previous turbojet experience as an F-4 pilot in the U.S. Air Force.

The pilots of flight 105 reported for duty on September 6, 1985, by telephoning their dispatch office in Appleton, Wisconsin, from the Midwest Express flight office at Mitchell Field in Milwaukee. It was the second day of a scheduled 2-day trip. The pilots shared captain responsibilities by alternating days as captain. The pilot who occupied the captain's (left) seat and assumed the responsibilities of captain on September 6, 1985, served as first officer on the preceding day. Similarly, the pilot who was the first officer on the accident flight had assumed the responsibilities of captain on September 5, 1985. Midwest Express reported that it was very unusual for two of their line captains to fly together, although check airmen flew with other captains fairly frequently (7-8 times per month). The captain and first officer of flight 105 had flown together before their current 2-day trip.

A review of both pilots' recent past activities revealed no evidence of medical problems or life situational stress problems which were present at the time of the accident. Their eating and resting habits were not remarkable.

The captain's most recent simulator proficiency check was on February 6, 1985, at Republic Airlines, and his most recent DC-9 line check was performed by a Midwest Express check airman on March 6, 1985. He completed recurrent DC-9 ground training on May 11, 1985. The captain's simulator training records reflected that "Takeoff with Simulated Powerplant Failure" was practiced in 12 sessions, "Approach to Stalls" was practiced in 12 sessions, and "Powerplant Failure/Fire" was practiced in 10 sessions. His flight instructor at Republic Airlines said the captain practiced one simulated engine failure on takeoff on a training flight, but FAA records indicated that he was not checked on that maneuver in the airplane during his type-rating checkride.

The first officer received his captain upgrade training at Republic Airlines. He also received check airman training at Republic Airlines in June 1984. However, his training records did not show that he had received all of the required check airman ground training. The FAA Principal Operations Inspector, who was assigned oversight responsibilities at Midwest Express, accepted the verbal assurance of the carrier that the required training was completed, without checking the training records of the pilot. After the pilot's ability to conduct check airman responsibilities was evaluated on May 14, 1985, he was authorized to perform proficiency and line checks in the DC-9 airplane and flight simulator. The Safety Board established that the check airman training records were incomplete. Whether the required training was conducted, but not documented in the training records, could not be established.

The first officer's most recent proficiency and line checks were completed on August 26, 1985, and March 21, 1985, respectively. Both checks were conducted by Midwest Express check airmen. The first officer's most recent DC-9 ground training was completed on November 10, 1984. Training records indicated that the first officer practiced "Takeoff with Simulated Powerplant Failure" in 15 simulator sessions, "Approaches to Stalls" in 12 simulator sessions, and "Powerplant Failure/Fire" in 14 simulator sessions. His flight instructor at Republic Airlines said he gave the first officer a simulated engine failure during climbout at least once in the airplane. He did not recall the details of the flight, but he said that he normally simulated an engine failure after takeoff in the airplane at 300 to 500 feet a.g.l. by retarding the throttle to a point (above 67 percent N2) where the engine would not unspool. 8/

Neither pilot had experienced an engine failure in his DC-9 line flying experience. Both pilots were "trained to proficiency" during captain upgrade training at Republic Airlines and were considered by their peers and instructors to be excellent pilots.

Midwest Express did not provide its pilots with a specific course on cockpit resource management (crew coordination), but training and management personnel stated that the applicable principles were stressed in the training of each pilot.

1.6 Aircraft Information

1.6.1 Aircraft and Engine Historical Information

N100ME, a McDonnell Douglas DC-9-14, serial No. 47309 (fuselage No. 393), was owned and operated by Midwest Express Airlines, Inc. Midwest Express Airlines is owned by K-C Aviation Inc., a wholly owned subsidiary of the Kimberly Clark Corporation. Midwest Express acquired N100ME from K-C Aviation on June 8, 1984, and operated the airplane until the date of the accident. According to Midwest Express records, the total airplane operating hours and cycles were 31,892 hours and 48,903 cycles, respectively, at the time of the accident.

N100ME was manufactured in 1968 and was delivered to the Linea Aeropostal Venezolana (LV) on October 23, 1968. It was sold to Aerovias Venezolanas, S.A. (Avensa, VE) on October 15, 1976, and then to K-C Aviation on January 20, 1983.

A review of the maintenance records for N100ME indicated that the airplane had been maintained in accordance with Midwest Express Airlines procedures and FAA regulations. On the day of the accident, the airplane was being operated with two deferred maintenance items in accordance with the minimum equipment list (MEL): left auto temperature control inoperative (MEL No. 99, dated August 28, 1985) and right cockpit flourescent light switch inoperative (MEL No. 100, dated August 28, 1985). There were no deferred items related to the powerplants or to the flight control systems. The maintenance records indicated that the requirements of all applicable Airworthiness Directives had been met. Midwest Express maintenance records indicated that inspections and checks required to assure continuous airworthiness of N100ME had been accomplished according to schedule.

8/ "Unspooling" refers to the rpm of the high pressure compressor (N2) dropping to idle rpm.

N100ME was equipped with two Pratt & Whitney model JT8D-7B turbofan engines. Neither engine was part of the equipment on the airplane when it was delivered in 1968. The left and right engines had accumulated 8,391 hours and 5,935 hours, respectively, since their last engine heavy maintenance (EHM). The left engine, S/N P657718, was installed on N100ME on August 19, 1984. The right engine, S/N P654106, was installed on N100ME on January 13, 1983.

The last recorded EHM of the right engine was performed at Air Carrier Engine Service (A.C.E.S.), now AeroThrust Corporation, in Miami, Florida, in September 1979. Engine records showed that the high pressure (H.P.) compressor 9-10 stage removable sleeve-type spacer (P/N 557340, S/N DAL 81374) from another engine (S/N P657255) was installed in engine S/N P654106 (later the right engine on N100ME) at that time. (See figure 1.) Engine records for the period before 1979 were not available to document the service history of the spacer; thus, the total operating time of the failed spacer was not known. The 9-10 stage H.P. compressor removable sleeve-type spacer is not a life-limited part.

Engine maintenance records showed that the owner of engine S/N P654106 returned the H.P. compressor to A.C.E.S. for refurbishment in October 1981. The H.P. compressor 9-10 spacer was repaired, inspected, and reinstalled following that rework. The A.C.E.S. Part Routing Tag for the 9-10 spacer, dated October 12, 1981, revealed the following operations, according to AeroThrust management:

> A "Reject" stamp dated October 9, referred to a damaged knife edge airseal. The airseal was reworked by blending 9/ the damaged area. The tubes were removed and the spacer nickel cadmium (NiCd) coating was stripped. The inside diameter was grit-blasted. The spacer was then examined using flourescent magnetic particle inspection (FMPI) equipment and passed inspection.
>
> The spacer was then replated (although not signed off) and the tubes were reinstalled. The spacer was machined and inspected one more time before installation in the engine.

There was no record of the nature of the previous damage which had necessitated the rework. The specifications regarding airseal blending of the 9-10 spacer allowed machining down to the inside radius, above the pedestal, to a maximum width of 2 inches in one area, or a maximum width of 4 inches for all areas. There is no record of the amount of blending that was performed.

On the day of the accident, the right engine had been in service 20,207 hours. It had operated 3,792 hours and 2,584 cycles since the 1981 H.P. compressor refurbishment. No major repairs had been performed on the right engine since its installation in January 1983, and no discrepancies had been noted for the right engine in the 30 days before the accident.

The left engine, S/N P657718, was purchased by Midwest Express from Ansett Airlines (Australia) in May 1984. The engine was inspected, test run, and determined to be serviceable by AVIALL of Dallas, Texas, before it was installed in the left position of N100ME on August 19, 1984. The left engine had been operated 23,939 hours and 25,394 cycles before the accident flight. No major repairs were noted in the engine log since the August 1984 installation, and no discrepancies were recorded for the left engine in the 30 days before the accident.

9/ Blending is a term used to describe machining to remove or smooth a damaged area.

Midwest Express used an in-flight monitoring program to track the performance of its JT8D engines. Review of the engine monitoring records from July 8, 1985, through September 3, 1985, revealed no adverse trends that would indicate a performance problem in either engine installed on N100ME.

1.6.2 Certification of the DC-9-14

The DC-9-14 was certificated as a transport category aircraft on November 23, 1965. Part 4b, Airplane Airworthiness Transport Categories, of the Civil Air Regulations required that the manufacturer:

- o Demonstrate that the airplane was "safely controllable and maneuverable during takeoff, climb, level flight, descent and landing" (4b.130(a)).

- o Demonstrate that it was possible to make a smooth transition from one flight condition to another, including turns and slips "without requiring an exceptional degree of skill, alertness or strength on the part of the pilot . . . under all conditions of operations normally encountered in the event of sudden failure of any engine" (4b.130(b)).

- o Demonstrate that, while holding the wings approximately level, it was possible to execute reasonably sudden changes in heading, in either direction, without encountering dangerous characteristics, even with an engine inoperative. Also, the manufacturer was required to demonstrate that it was possible to execute 20° banked turns with and against the inoperative engine. (4b.132); and

- o Determine a minimum control speed (Vmc) 10/ so that when the critical engine was suddenly made inoperative, at that speed, it was possible to recover control of the airplane, with the engine still inoperative, and maintain straight and level flight at that speed, either with zero yaw or, at the option of the applicant, with an angle of bank not in excess of 5°. Vmc speed was not to exceed 1.2 times the stalling speed of the aircraft (4b.133). During that maneuver, take-off, or maximum available power, was to be maintained on the remaining engine.

1.6.3 Airplane Flight Control Systems

The DC-9-10 series airplanes (including the -14 model) have conventional aileron, rudder, and elevator control systems. The horizontal stabilizer is adjustable for longitudinal trim. Lateral control is aided by hydraulically operated flight spoilers. The rudder normally is powered hydraulically with automatic reversion to cable operated aerodynamic tab control when hydraulic power is not available. A yaw damper aids directional stability, but a yaw damper operation is not required for flight by the minimum equipment list.

Additionally, a mechanism limits rudder travel at speeds above approximately 176 knots. Cable and hydraulic system redundancy is provided to minimize the risk of loss of aircraft control in the event that individual component parts of the control system are

10/ The minimum control speed with the critical engine inoperative.

disabled in flight. The main control cables, the trim cables, and the hydraulic lines, which pass through the aft fuselage adjacent to the engines, are located below the cabin floor, well below the top of the right engine. (See appendix G for a detailed discussion of relevant flight controls and aircraft systems operation.)

1.7 Meteorological Information

At the time of the accident, the sky over General Billy Mitchell Field was clear. Weather conditions in the Milwaukee area were characterized by scattered clouds and moderate southwesterly winds. The surface weather observations at General Billy Mitchell Field were:

> 1451, Surface Aviation: Clear, visibility—10 miles; weather—none; temperature—89° F, dew point—76° F; wind—230° at 15 knots, gusting to 20 knots; altimeter—29.83 inHg; remarks—few cumulus and cirrus east.
>
> 1540, Local: Clear, visibility--10 miles; weather—none, temperature--90° F, dew point—76° F; wind—220° at 15 knots, gusting to 20 knots; altimeter--29.83 inHg; remarks—few cumulus, aircraft mishap.

Based on the 1451 observation, the density altitude was determined to be 3,200 feet.

A wind gust recorder, 11/ operated by the National Weather Service at Mitchell Field and located at the intersection of runways 19R and 25L, showed a range of wind speeds from 9 to 22 knots from 1500 to 1600. The wind decreased from 18 knots at 1515 to 10 knots at 1520 and then it rapidly increased to 17 knots at 1521:30 and dropped rapidly to 12 knots at 1522:30. At 1516, the Milwaukee tower local controller advised Midex 105 that the wind was from 210° at 16 knots.

1.8 Aids to Navigation

Not applicable.

1.9 Communications

There was no evidence of radio communication difficulties between flight 105 and Milwaukee Tower controllers on the day of the accident. The Daily Record of Facility Operations indicated that all air traffic control tower equipment was operating satisfactorily at the time of the accident.

1.10 Aerodrome Information

General Billy Mitchell Field is 723 feet above mean sea level (m.s.l.) and is located 6 miles south of downtown Milwaukee. It is served by five runways. Runway 19R was 9,690 feet long by 200 feet wide, and it was oriented to 187.1° magnetic. It had a concrete and asphalt surface which was wire combed and grooved. Runway 25L was 8,010 feet long by 150 feet wide, was surfaced with asphalt and concrete, and was grooved. The airport is certificated for air carrier operations under 14 CFR 139.

11/ A gust recorder (anemometer) records wind velocity only, and not the direction from which the wind is blowing.

Milwaukee Tower is equipped with an ARTS III 12/ terminal radar computer system which utilizes radar data obtained from an ASR-8 13/ radar located on the airport. Recorded radar data associated with the Midwest Express assigned transponder code 5631 were retrieved and utilized to reconstruct a track of the ground and flight progress of flight 105. The ARTS III radar data could not be used to reconstruct the tracks associated with nontransponder (primary) targets, such as engine debris.

1.11 Flight Recorders

N100ME was equipped with a Fairchild 5424 foil type analog flight data recorder (FDR), S/N 7379, and a Fairchild model A-100 cockpit voice recorder (CVR), S/N 875. The FDR sustained mechanical damage but revealed no evidence of internal exposure to fire or smoke. The magazine containing the foil recording medium was undamaged. All parameter and binary traces were present and active; however, the auxiliary binary traces, which are normally used to record indications of radio transmissions, were not functioning during the accident flight. The CVR casing suffered mechanical and fire damage but the recording medium was undamaged. The quality of the recording was good. All of the CVR channels were working.

1.11.1 Flight Data Recorder

The FDR was recovered from the wreckage and was forwarded to the Safety Board's Flight Recorder Laboratory in Washington, D.C. It contained indicated airspeed, indicated altitude, heading and normal acceleration 14/ data. (See appendix F.) Inspection of the FDR foil recording medium indicated that there was a gap in the data starting at FDR time 00:53.5 (1521:26.4). The gap was equivalent to about a 4-second time interval. At the end of the gap, several data points, normally recorded at 0.55-second intervals, were recorded as if they had occurred simultaneously.

The gaps in the FDR data during the accident flight were attributed to a jump in the foil position which probably resulted from airframe vibration and occurred about the time the right engine failed. The time correlation of the measured parameters was achieved by aligning the gaps in the recording. Subsequent correlation of the FDR and CVR data revealed that the "clunk" sound on the CVR occurred at the same time as the beginning of the gap.

1.11.2 Cockpit Voice Recorder

The CVR revealed that the takeoff appeared normal to the flightcrew. There was no recorded conversation to indicate that the captain relinquished control of the aircraft to the first officer, or that the first officer communicated any intention to assume control of the aircraft during the flight. The CVR did not record any conversation or other indications which would confirm the extent to which the crew recognized the nature of the emergency, nor did it reveal what actions were taken by the crew to respond to the emergency. (See appendix E.)

The No. 1 channel of the CVR was connected to the passenger intercom system. The recording was 32 minutes long but only the last 7 minutes were transcribed,

12/ Automated Radar Terminal System. The suffix, III, denotes a specific system capability.

13/ Airport Surveillance Radar.

14/ That component of inertial acceleration which is perpendicular to the airplane's lateral and longitudinal axes.

encompassing the time from engine start until the end of the recording. The transcript begins at 1514:33 c.d.t. with the start of the No. 2 engine. The engine power increase, associated with the commencement of the takeoff, occurred at 1520:43. The engine volume and frequencies, which were measured on a sound spectrum analyzer, seemed normal until 1521:26.4, when a loud "clunk" sound was heard. Almost immediately following the "clunk," the rpm of one of the engines decreased noticeably. At 1.2 seconds after the "clunk," the captain exclaimed, "What the # was that?" At 1.5 seconds after the "clunk," the rpm of the second engine began to decrease, but at a slower rate than the first. The captain asked, "What do we got here Bill?" There was no response from the first officer. Analysis of sounds recorded by the CVR revealed that the stall warning stickshaker activated at 1521:36.0 and continued until the end of the recording. Two seconds after the stickshaker activated the captain exclaimed, "Oh . . ." Shortly afterward, the airplane's altitude began decreasing rapidly. One flight attendant, exclaimed "Heads down" three times. The electrical power to the CVR was interrupted at 1521:38.8 for about 0.1 second. At 1521:41.7 (2/10 of a second before the recorder stopped) a single "whoop" could be heard from the ground proximity warning system.

1.11.3 CVR Sound Spectrum Examination

The CVR recording was examined using the NTSB Audio Laboratory's Spectral Dynamics SD-350 sound spectrum analyzer to document the sounds which were in frequency ranges normally associated with engine operation. Some of the sounds heard were in the 70-200 Hertz (Hz) range. Sounds produced by the rotation of the high pressure compressor (N2) of a JT8D engine are in this frequency range. Those sounds were measured starting at engine spool-up before takeoff and continued until 1521:41.

Sounds similar to those produced by the fan section (N1) of the JT8D engine (in a higher frequency range) were identified but were not heard until about 3 seconds before the loud "clunk" at 1521:26.4. The N1-type sounds, which were very faint and could not be heard after the stickshaker activated at 1521:36.0, were determined to have emanated from the left engine. Fan section speed was calculated by dividing the number of first stage fan section blades (30) into the blade passing frequency 15/ documented by the sound spectrum analyzer printout. Similar calculations were conducted for the N2 fan section. These calculations were used to evaluate the N1 and N2 values during the period in which the loud "clunk" was recorded on the CVR and beyond. The N1 and N2 values revealed that:

(1) The right engine rpm, as measured by N2, fell off rapidly immediately following the loud "clunk"; and

(2) The left engine rpm, as measured by N1 and N2, fell off at a slower rate starting about 1.5 seconds after the "clunk" sound.

1.11.4 Time Correlation of CVR, FDR, Radar, and Air Traffic Control Information

The data available from the CVR, the FDR, the air traffic control (ATC) transcript, and the recorded (ASR-8) radar data incorporated different reference times. The CVR timing (elapsed time) was correlated to the ATC transcript timing and the radar data timing, which were based upon universal coordinated time (UTC). The timing of the FDR was correlated with the radar data by comparing plots of radar and FDR-indicated altitudes which preceded the engine "clunk." The correlation between CVR and FDR data

15/ Characteristic blade passing frequency is assumed to result from the fan blades causing pressure pulses in the air during rotation.

was performed by overlaying the CVR time line over the plotted FDR data. Several points were time correlated such as the gap/engine clunk point, the 100-knot callout, the V1 callout, and the ends of the recorded CVR and usable flight data. (See appendix F.)

1.11.5 Static Pressure Error

At 00:57 FDR elapsed time (1521:30), the FDR data indicated an excessive increase in the climb-rate, while the vertical acceleration data indicated a reduction of normal acceleration forces from about 1 G to about 0.3 G. The reduced G load suggested forward control yoke input and a reduced climb rate, contrary to the recorded altitude data, but consistent with witness observations.

The rapid increase in FDR-indicated altitude revealed that the indicated aircraft climb performance was in error and contrary to the known performance characteristics of the airplane. It had been expected that a reduction in G load below 1.0, would have decreased the rate of climb, yet the FDR indicated a rapid increase in altitude. By integrating the accelerometer data, the maximum altitude which the airplane actually reached was determined to be about 1,400 feet m.s.l., not the indicated 1,570 feet m.s.l. Douglas Aircraft Company flight test data showed that the difference, 170 feet, could have resulted from static pressure error. Information, interpolated from Douglas flight test data, revealed that the 170-foot indicated altitude error (higher than actual) was consistent with a sideslip 16/ angle of about 15°. Such a sideslip, according to the Douglas data, would produce a static pressure error and false indications in the instruments which are dependent upon pitot-static information. The static pressure source for the FDR is the airplane's alternate static pressure source. The captain's and first officer's altitude and airspeed instruments (and vertical speed) used the normal pitot static system, which is less sensitive to sideslip-induced errors. Thus, while a 15° sideslip would cause the FDR to record airspeed about 14 knots too high, the same sideslip would cause the cockpit instruments to reflect only about 2/3 of the FDR airspeed (9 knots) and altitude error (113 feet).

1.11.6 Aircraft Flight Profile Information Based On Recorded Data

The FDR foil revealed that the takeoff roll and liftoff were normal, with liftoff occurring near the intersection of the midfield taxiway and runway 19R, about 4,200 feet from the start of the takeoff roll. Rotation to the takeoff attitude occurred at 140 knots. N100ME accelerated to 168 knots with a rate of climb of about 3,000 feet/minute, indicating a normal two-engine initial takeoff flightpath. N100ME was about 7,600 feet down the runway when it reached a height of 450 feet above the ground and when the right engine failed. Radar data indicated that the airplane was near the left edge of runway 19R at engine failure. This displacement left of the runway centerline was considered in evaluating the distribution of engine parts, which were found near the runway, in analysis of the trajectory of engine parts. The heading trace showed that N100ME continued essentially straight ahead for the first 4 seconds after the right engine failure. Radar data confirmed the tracking of the airplane essentially straight ahead.

Four seconds after the right engine failure, the FDR heading trace began to deviate substantially to the right (from about 194° to a heading of 214°) over a 5-second

16/ Yaw is the rotational movement about the airplane vertical axis from a fixed reference point. Sideslip is the sideward movement of the airplane, where the relative wind is offset to the left or right of the longitudinal axis of the airplane.

period (4° per second). The heading then deviated to the right at a more rapid rate (to 260°) in the next 3 seconds (15° per second). Comparing the heading change to the radar track of the flight revealed that part of the heading change, that is, the difference between the actual track and the heading, was due to sideslip. The sideslip began about 4 seconds after the right engine failure and increased rapidly in the next few seconds.

For about 3 seconds after the right engine failure, the FDR vertical acceleration trace remained at about 1 G. It then dropped sharply to about 0.3 G in the next second before increasing to a value of 1.8 G. The FDR and aerodynamic data indicated aircraft stall at the point where vertical acceleration reached 1.8 G.

Based upon a 14-knot FDR airspeed error due to sideslip and induced static pressure error, the actual airspeed loss from right engine failure to stickshaker would have been about 17 knots. Correcting the FDR data for sideslip and static pressure error revealed that the aircraft stalled about 148 knots equivalent airspeed (KEAS), 17/ or about 156 KIAS (crew instruments).

On the accident flight (20° flaps), the 1 G stall speed was 114 KEAS and the predicted stickshaker speed was 118 KEAS. When aircraft loading is in excess of 1 G flight, the aircraft will stall at a higher speed (accelerated stall), consequently increasing the stickshaker activation speed. Similarly, when the aircraft is rolling, the stickshaker speeds increase. The following table reflects the predicted variations in stickshaker speed as functions of load factor and roll rate. The stickshaker stall warning device is dependent on angle of attack. Deceleration at a rate in excess of 1 knot per second and/or abrupt pullup maneuvers would reduce the 4-second warning time normally provided by the stickshaker stall warning system.

Roll Rate Degrees/Second	Stickshaker Speeds (KEAS) with 1.0 G Load Factor	Stickshaker Speeds (KEAS) with 1.5 G Load Factor
0	118	144
5	120	146
10	122	148

1.12 Wreckage and Impact Information

1.12.1 General

N100ME struck the ground in a clearing, in a relatively level, partially wooded field. Ground elevation of the initial impact point was about 680 feet m.s.l. Initial contact was at the northern end of a 275-foot-long wreckage path where there were two parallel gouges about 14 feet apart and which were initially 4 to 5 inches wide. One gouge was 28 feet long, and the second gouge was 80 feet long. Both gouges were oriented to 185°. Pieces of the right elevator and horizontal stabilizer were imbedded at a 90° angle to the ground along the length of the 28-foot gouge. The width of the 80-foot gouge gradually increased to 5 feet 5 inches at the southernmost end and contained right wing fragments. Pieces of the right wing tip were identified at the north end of the 80-foot gouge. The right engine was lying across the midpoint of the gouge. Beyond the initial gouges, the remainder of the wreckage of N100ME was strewn about a 200-foot-wide path.

17/ At these speeds and altitudes, KIAS and KEAS are generally considered to be the same, if there are no instrument errors or static source errors. A static source error would create a difference between KEAS and KIAS.

The wreckage was fragmented and was largely consumed by fire. Airplane pieces, ground, and trees in this area were blackened and scorched by fire. Pieces of all flight control surfaces and the extremities of the airplane, such as nose, wingtips, tail surfaces, and engines, were found in the impact area.

Engine-related parts from the right engine were found up to 200 feet to the left side and between 7,400 and 8,200 feet south of the north end of runway 19R. The parts included compressor blades from the 9th and 10th stages of a Pratt & Whitney JT8D engine and parts, which totaled 90 percent, by weight, of a 9th to 10th stage (9-10) high pressure compressor spacer. With the exception of the engine-related parts found on and adjacent to runway 19R, the wreckage of N100ME was recovered from the airplane impact area. (See appendix D.)

The attitude and flightpath angle of the airplane at impact were estimated by pictorially aligning the ground scars with the corresponding airplane parts. Using a scale drawing of the airplane, the right wingtip was placed at the north end of the long ground scar and the flightpath of the right horizontal stabilizer was aligned with the shorter ground scar. The airplane drawing was then rotated to bring its flightpath into alignment with the end of the long ground scar. Thus, the Safety Board determined that flight 105 had impacted in about a 90° right roll with the nose about 29° below the horizon in a 31° right yaw. The flightpath immediately before impact was determined to have been about 60° downward.

1.12.2 Details of Wreckage Examination

Fuselage.--The fuselage was fragmented and burned. Most of the identifiable nose section components were found near the south end of the wreckage path. Aft fuselage pieces were found from the north end of the wreckage path to a point 156 feet from the initial impact point. Pieces of the aft fuselage were examined for potential punctures which might have occurred if parts ejected from the right engine had contacted the fuselage before ground impact. Several pieces were submitted to the Safety Board's Materials Laboratory for further examination. For example, punctures were found in the fuselage at about fuselage station (F.S.) 894, 6 inches below the right engine pylon fairing. In the vicinity of the punctures the fuselage skin was extensively torn. However, none of the fuselage skin sections which contained suspicious-looking punctures were adjacent to hydraulic lines or major control cables.

Wings.--The wing structure was destroyed with pieces strewn about the crash site. The largest pieces recovered were from the left wing and included a 34-foot-long outboard section with the aileron and trim tab attached, although they were battered and partially consumed by fire. Both angle of attack vanes (stall warning system lift transducers) were recovered but the right vane had separated from the wing and was damaged. A 9-foot piece of the left wing leading edge, from approximately the vortilon 18/ position to the outboard end, was intact.

The vortilon was partly attached to the wing with portions burned away. The wing leading edge surfaces available for examination were smooth and revealed no evidence of surface corrosion. Several pieces of right wing leading edge were found to be smooth and free of corrosion.

18/ Vortilon (vortex generating pylons) are installed on the wing lower surfaces to provide airflow control.

Three battered and fire-damaged right aileron pieces were found near the initial impact area. Portions of both right aileron control tabs were found within the aileron structure. The left aileron, with portions of the control tabs attached, was battered, but intact and attached to the largest piece of the left wing.

All four flight spoilers were attached to their respective actuators and were found in stowed positions. All four spoiler actuators were retracted and locked. The left-hand spoiler bypass valve operating handle was found in the ON position with the lock-pin in place. The right-hand valve operating handle was missing, but the indicator was pointing to ON.

Right flap pieces were found in the initial impact area. All flap hinges and the flap hydraulic actuators were separated from the flaps. The left flap was recovered in two pieces. Each piece was relatively intact except for some fire damage at the trailing edge of the outboard piece. It was not possible to confirm the preimpact flap position from the remaining flap fragments. Both left flap actuators were recovered. Internal examination of the cylinders at the Safety Board's Materials Laboratory did not reveal marks made by the pistons at the moment of impact. Examination of the piston rods revealed bends in three rods 2 3/4 inches from the piston rod end. Comparison of McDonnell Douglas data and measurements from an airplane similar to the accident airplane revealed that the piston rods were in a position corresponding with 28° to 29° extension when they were bent.

Crew conversation, recorded by the CVR, indicated that the flaps were set at 20° for takeoff and did not reveal any indication that the flap position was changed after takeoff.

Empennage.--The pitch and directional (yaw) control system pieces were battered and fire damaged. There was, however, no evidence of foreign object damage (FOD) to the actuators, push-rods, or hinge brackets. All fractures appeared typical of overload separations. The captain's and first officer's fractured left rudder pedal support arms were removed and sent to the Safety Board's Materials Laboratory for detailed examination.

The vertical stabilizer was found resting on its right side, separated from the fuselage, largely intact from its lower attachment points to the horizontal stabilizer jackscrew. Much of the left side was severely fire damaged. No punctures were found in the remaining left side skin. The right side skin of the vertical stabilizer was sooted and discolored but largely was intact. Punctures and gouges were examined carefully for evidence of contact or damage caused by ejected engine parts. All of the observed punctures were in areas which did not contain control system components. Some of the punctures and gouged areas were removed for detailed laboratory examination.

About 12 feet of vertical stabilizer rear spar structure (from 2 feet below the fuselage/stabilizer junction to 10 feet above that junction) was intact. The spar was heat damaged and had partially melted away. This portion of the rear spar revealed no evidence of penetration or gouging damage. The two hydraulic lines for the elevator power boost system were still routed along the rear spar; the lines were intact except at the top and bottom of the stabilizer where they were broken and distorted. Broken portions of the upper and mid-hinge bracket bolts for the rudder were still mounted to the vertical stabilizer. The fracture surfaces were typical of overload damage.

The rudder was nearly detached from the vertical stabilizer and had suffered extensive fire damage. A 2-foot piece of rudder leading edge remained attached to the vertical stabilizer at the lower rudder support post. It was heavily fire damaged. The rudder sector linkage mechanisms at the base of the rudder were still attached to the rudder control tab, although heavily heat damaged. The control tab input arm at the base of the tab torque tube was broken. The bracket arm mount at the bottom of the torque tube also was broken about 4 inches from the centerline. The bracket and arms for the hydraulic actuator linkages to the rudder were intact; there was no evidence of preimpact FOD in this area. The rudder hydraulic actuator was still attached to the rudder drive arm.

A rudder section, approximately 6 feet long, which consisted of leading edge material back to the front spar and center and upper hinge areas, was recovered. The hinge brackets were broken; however, pieces of bracket structure were still attached by the pivot bolts of both the center and upper hinges. The fracture surfaces were typical of overload. The rudder damper was still attached and was movable with normal resistance. The damper control arm which attached to the vertical fin was broken. A 1 1/4- by 1/8-inch horizontal cut was found in the rudder leading edge skin approximately 2 1/2 inches above the center hinge area. The cut was at the crown of the leading edge and had penetrated the skin; however, a plate beneath the surface was not penetrated. No other penetration damage was noted.

A 17-inch piece of rudder control tab leading edge (from the base pivot point to the lower hinge) was recovered. It was heavily fire damaged; however, it exhibited no gouge damage.

The yaw damper was removed from the wreckage and disassembled. No evidence of preimpact failure or malfunction of the yaw damper was found.

The left horizontal stabilizer was severely burned. The largest remaining intact portion was a 20- by 36-inch rear center section with a piece of vertical stabilizer pivot structure attached. The right horizontal stabilizer was disintegrated. The majority of the identifiable pieces were recovered from the initial impact ground scar. No evidence of foreign object penetration or corrosion was observed in the pieces that were available for examination.

The primary and alternate electric trim actuators and planetary gearbox had broken off the jackscrew that is used to adjust the position of the horizontal stabilizer in flight. The direction of the fracture was consistent with the attitude at which the aircraft struck the ground. The length of the jackscrew extension corresponded to 2.05° airplane nose-up trim, close to 2.2 units nose-up trim set by the crew before takeoff.

Seven fragments of the right elevator, accounting for all but the aft area at the inboard end (which was burned away), were recovered from the wreckage path. There were no punctures through the recovered elevator pieces. An area of the lower trailing edge surface, which contained scrape marks, was removed for laboratory examination. There was no evidence of FOD in a 47-inch section of right elevator control tab which had separated from the elevator.

A 12-foot piece of left elevator leading edge was attached to the horizontal stabilizer. The leading edge contained no punctures. The remainder of the left elevator was consumed by fire. Similarly, the left elevator control tabs were completely burned away except for portions of their leading edges.

The elevator control tab bellcranks were still attached to the torque tubes within the horizontal stabilizer, although they were heavily fire damaged. The bellcrank ends of the elevator control cables were still attached although the other ends of the cables were broken. The broken ends had parted in a manner consistent with tension overload. On the remaining elevator and horizontal stabilizer pieces, which were not consumed by fire, no puncture marks were evident.

Flight Control Linkages and Cables.--The extensive breakup of N100ME following ground impact resulted in broken and distorted bellcranks, sectors, pulleys, and cables which had been associated with the cable control system. Four cables, which were for primary control of the elevator and rudder, were recovered from the left side of the fuselage in the area of the lavatories and outflow valve and aft of the aft pressure bulkhead. The broken ends of the cables were typical of tension overload failures. Two rudder trim cables and a stabilizer feedback cable, which had been routed along the right side of the aft fuselage, were examined. None of these cable fractures disclosed evidence of preexisting failure or material defect.

A 40-foot piece of elevator control cable, routed from within the vertical stabilizer, revealed a fracture consistent with tensile overload. Two stabilizer position cables, which had been routed through the vertical stabilizer, also had broken ends which were typical of tension overload failures.

About 200 feet of primary elevator and rudder control cable were identified and examined with regard to fracture mode and for mechanical damage. Another three sections of primary control cable, each about 22 feet long, were recovered from the vicinity of the outflow valve and were similarly examined; however, the cables could not be precisely identified. All primary elevator and rudder cable breaks were typical of tensile overload or were brittle fractures due to overheating. The sections of cable which had broken strands or which were otherwise suspect were submitted for Safety Board laboratory examination. No evidence of preexisting damage was noted.

About 115 feet of rudder trim and stabilizer position cable were examined, disclosing tensile overload and brittle fractures associated with overheating. One piece of right rudder trim cable similarly revealed tensile fractures and a brittle fracture associated with overheating.

The elevator sectors at the top of the vertical stabilizer were each in one piece but were fire damaged. The right elevator torque tube was intact with a broken end of the elevator control tab rod attached. The rod end fracture was typical of overload failure. The left elevator torque tube, including the entire elevator control rod, was still attached to the top section of the vertical stabilizer. The rod was straight with the attachment bolt to the tab still in place. The tab end of the rod was heat damaged and the tab structure had melted from around the rod end. The control rods for the left elevator geared tab were still attached to the left elevator leading edge structure. Both rods were straight with the aft attachment bolts intact. The elevator gear tab attachment brackets had melted from around the geared tab rods.

The right elevator geared tab rods were still attached to the elevator structure. Both ends of the inboard rod were still attached, one to the elevator and the other to a piece of tab structure. The outboard rod was attached at the forward end to the elevator structure but was broken at the aft end of the rod end fitting. The fracture was typical of bending overload. The right elevator control tab rod was not recovered except for the forward attachment fitting which was still attached to the torque tube structure.

Hydraulic Systems.--The hydraulic systems were fragmented and burned as a result of impact forces and the effects of the postcrash fire. The hydraulic systems were examined to determine whether there had been any interruptions to hydraulic power before impact. The hydraulic reservoirs exhibited fire and impact damage. Similarly, numerous hydraulic lines, the right auxiliary hydraulic pump, and the right hydraulic system pump/motor all exhibited extensive impact and fire damage. Eight hydraulic accumulators were recovered but were fire and impact damaged. One accumulator indicated a pressure of 500 psi. Both hydraulic system filters contained burned hydraulic fluid; the magnetic plugs were clean.

Both elevator augmentor cylinders and the right elevator control valve were tested and found to operate normally. The left elevator control valve was fire damaged to the extent that it could not be tested. The postimpact condition of the elevator augmentors did not allow the identification of the preimpact positions.

The rudder power shutoff valve, valve sector, and crank were recovered near the airplane impact point. Examination of the rudder power shutoff valve revealed a bent control rod and discoloration which were consistent with rudder hydraulic power on. Hydraulic fluid was within the actuator resevoir. A measurement of the rudder power actuator (actuator eyebolt to rudder crank) was equivalent to 1.5° to 1.75° rudder trailing edge left of center. The rudder trim and load feel mechanism measurement was equivalent to the rudder trailing edge being 2.5° left of center. The position of the "Q" bellows hook to the rudder power cylinder actuator pushrod indicated neutral rudder. The gripper arms of the rudder tab lockout mechanism were found essentially against the roller, indicating that the mechanism was in the manual rudder position. Loss of hydraulic pressure would account for the rudder tab lockout going to the manual rudder position. The rudder hydraulic actuator exhibited no evidence of preimpact damage. The laboratory examination of the hydraulic pressure and return lines (from the rudder power actuator to about 40 inches forward of cant station 989.4) did not reveal evidence that the fractured areas had been damaged because of another object impacting the lines.

Landing Gear.--All three landing gear had separated from the aircraft structure but remained in the wreckage area. All three landing gear actuators were attached to their respective gear struts and were in the gear "up" positions. All six tires were intact. Recorded cockpit conversation disclosed that the landing gear were retracted after takeoff and did not reveal any indication that the landing gear were subsequently extended by the crew.

Right Engine.--The right engine was found resting on its right side, still attached to a portion of the pylon structure, about 40 feet south of the initial impact point of the airplane. The engine revealed evidence of a frontal impact with the ground which left dirt deposits within the right side of the inlet case. The engine exhibited impact damage but was intact from the inlet case through the thrust reverser. The engine thrust reverser was found in the stowed position.

Examination of the right engine revealed that the 9-10 stage compressor spacer had ruptured and separated from the engine, liberating all of the 9th and 10th stage compressor blades. The blade outer shrouds showed evidence of severe abrasion, typical of airfoil release at high rotational speed. There was an opening in the rear skirt of the intermediate case from the 11 to 1 o'clock position (viewed looking forward), which was 4 inches wide axially and 7 inches long circumferentially in the plane of rotation of the missing 9-10 spacer. A piece of vane shroud was protruding through the rear skirt into the fan airflow duct. There were no other holes through the compressor case. The internal damage was consistent with a sudden failure initiated by the rupture of the 9-10 spacer.

Metalization of fuel nozzles and burner can domes, thermal cracking of first stage turbine blades, and metallographic laboratory tests showed that the first and second stage turbine blades had been subjected to temperatures well in excess of normal operating temperatures; all were consistent with turbine overtemperature operation, secondary to the effects of the spacer rupture.

Examination of the 12th stage compressor blades revealed that the majority of the airfoil fractures exhibited tensile or shear characteristics. Nine blades, however, showed evidence of relatively shallow fatigue progressions with multiple origins along convex airfoil surfaces. The fatigue was typical of low cycle, high stress cracking. None of the fractures appeared to be primary in nature.

Most fan blades which were in areas of case deformation were buckled. The third and fourth stage turbine blades similarly were buckled in a manner typical of little or no rotation of the rotors at impact. The EPR transmitter linkage indicated 0.95 (sub-idle) at impact. Examination of the engine revealed no evidence of bird ingestion or other significant FOD.

Both the upper and lower right engine cowlings were extensively damaged and had broken apart. Some pieces of the upper cowling, however, remained attached to parts remaining from the lower cowling, including:

(1) Three of the four inboard upper cowling hinges were latched, with portions of the apron and upper cowling attached. The fourth hinge was not latched but was intact; and

(2) All four outboard upper cowling latches were latched, with portions of the upper and lower cowling attached.

A 3-foot section of the forward upper cowling was recovered and contained a hole, 2 square inches in size, which appeared to have progressed from inside to outside the cowling. The location of the hole was determined to have been 16 inches forward of the plane of rotation of the 9-10 stage compressor spacer. None of the cowling pieces which had been adjacent to the hole in the engine were identifiable because of extreme distortion and tearing of the cowling. There was no evidence that the right cowling had opened before ground impact.

Left Engine.--The left engine was found in a wooded area in heavy vegetation, about 180 feet south of the right engine and near the south end of the wreckage path. The engine had sustained severe impact damage in the inlet area between the 3 and 9 o'clock positions (viewed looking forward); the full length of the engine case had been damaged or distorted by impact. The front fan case was ovalized over a wide area centered about the 4 o'clock position. Markings, such as blue paint smears, rivet witness marks, and red paint transfer on the right side of the engine nose cowl, were consistent with impact forces occurring at the 4 o'clock engine position. The inlet case was found about 30 feet north of the left engine and the nose cowl was 20 feet farther north. The rear fan case was split at the 12:30 to 2 o'clock position; the front flange was crushed rearward at the 4 o'clock position. The upper and lower cowlings were attached to the engine.

The left engine main gearbox had sustained a frontal impact with a right to left direction of the impact force which had partially dislodged the gearbox from the engine. The fuel control unit was separated from the fuel pump and gearbox. The gearbox right mount was shattered, and the right side of the gearbox was badly damaged. The cross shaft was partially dislodged. The linkages associated with the power lever and fuel control shutoff valve were bent and broken precluding an accurate determination of the preimpact positions of those controls.

Most of the first stage fan blades were fractured at the airfoil root. The fracture surfaces revealed no evidence of fatigue. First stage blade tips were rolled over, consistent with the effects of relatively high rotor speed at impact. The second stage blades which remained in the disk were bent opposite the direction of rotation of the disk. Likewise, the fifth stage blades were extensively bent opposite the direction of rotation of the fifth disk. The amount of compressor rotation, which corresponded with blade damage at the time of airplane impact or during engine impact(s), could not be determined from the fan blade damage.

Only five third stage blades remained in the disk. Many of the liberated fan blades were found near the airplane impact point, and others were found near the point where the engine came to rest. The sixth stage blades all revealed evidence of tensile or shear fracture. There were no missing seventh stage blades.

Fragments of aircraft insulating material were observed on the leading edge of some seventh stage blades. Pieces of seat upholstery (seat leather and foam) were found jammed inside a fractured fan inlet guide vane. Three adjacent fan inlet guide vanes had blue paint smears and one vane had white paint smears. These paint smears were consistent with the airplane fuselage color scheme.

In the eighth disk, 29 blade roots remained in their slots; all other blades were liberated. Many outward perforations were observed in the intermediate case rear inner duct in the plane of rotation of the eighth and ninth stage rotors. Eighth and ninth stage stators were found impacted into the shroud.

Some of the eighth and ninth stage blades exhibited evidence of high stress, low cycle, reverse bending fatigue adjacent to their platforms with multiple origins on the convex and concave airfoil surfaces. These fracture surfaces were typical of the fractures referenced in the Pratt & Whitney JT8D Engine Repair Manual. (See appendix H.) A Pratt and Whitney Product Support Engineer testified that the fractures described in the maintenance manual were a result of improper engine reversing on the ground, which in turn had caused compressor stalls. However, he testified to one exception where such damage was found after a blade root failure. He said that Pratt & Whitney was not aware of any incident where it had occurred secondary to compressor stalls which had occurred in flight. The Pratt and Whitney engineer stated that any engine which was subjected to repeated stalls over an extended period of time, could produce such damage. He testified that in accident investigations, such damage had not previously been found to have occurred secondary to ground impact when an engine had previously been operating at high rpm.

A balled-up, marble-sized piece of titanium alloy, which was identified as an eighth stage blade root, was jammed between two adjacent stator vanes in the 11th stage stator assembly. No other compressor blades exhibited similar deformation. An unidentified airfoil section, which resembled part of a blade from the high pressure compressor, was trapped between the eighth stage stator support rail and a slightly buckled section of the rear skirt. Sharp rotor blade imprints were observed on the trailing edge of the fifth, seventh, and eighth stator assemblies.

The left engine burner can domes, fuel nozzles and transition ducts, and first stage turbine vanes and blades contained titanium-based alloy splatter deposits. The vane airfoils and blades did not exhibit evidence of overtemperature operation.

The left engine examination revealed no evidence of bird ingestion. Neither was there any ingestion of dirt or leaves within the engine. The main fuel shutoff valve for this engine was 80 percent open. The thrust reverser was found in the stowed position.

Cockpit Indications.--The majority of the cockpit instruments, indicators, lightbulbs, and control levers were too badly damaged to reveal meaningful information. A flight director indicator indicated a 60° right bank and a 10° nose-low attitude. The left and right EPR indicators indicated 0.8 and 0.88, respectively. More reliable EPR indications were obtained by examination of the EPR transmitters, revealing gear train positions consistent with 1.35 and 0.95 EPR for the left and right engines, respectively.

The rudder trim knob was intact on a section of the control pedestal and was found in the 1 unit left position. A scratch mark was noted on the indicator scale at a position between 1 unit left and the neutral position. The aileron trim wheel on the same pedestal was in a position of about 1 unit left wing down.

1.13 Medical and Pathological Information

Postmortem examinations of the airplane occupants were conducted by the Medical Examiner of Milwaukee County, Wisconsin. No evidence of disease processes which would have affected the ability of the cockpit crewmembers to operate the airplane were identified. The cause of death of all victims of the crash was reported as "multiple massive injuries to the head, torso and extremities." Tissue samples from the two pilots, one flight attendant, and two passengers were submitted for toxicological testing. However, the tissue samples were contaminated with fuel and other substances, which rendered the results of the toxicological testing meaningless.

1.14 Postcrash Fire and Emergency Response

The wreckage revealed no evidence of in-flight fire. Evidence indicated that any fire associated with the right engine was contained within the engine. N100ME exploded following impact and was largely consumed by the effects of a postcrash fire.

Crash/fire/rescue (CFR) response was effected by the Airport Fire Department, the 440th Air Force Reserve Fire Department, the 128th Air National Guard Fire Department, the Milwaukee County Sheriff's Department, the Oak City Fire and Police Departments, and the Milwaukee County Fire Department. Firefighters witnessing the events immediately preceding the crash began to launch the 440th Air Force Reserve Tactical Airlift Wing Fire Department at 1521 before their official notification. Air traffic control tower personnel notified the Airport Fire Department at 1522, triggering the airport's emergency plan. Response to the crash site was prompt and orderly with the first units onsite and discharging fire extinguishing agent at 1524. There was no difficulty reaching the crash site and sufficient equipment was available to extinguish the postcrash fire. The principal fire area and wreckage had been cooled down by firefighters by 1528.

1.15 Survival Aspects

Impact forces and the postcrash fire destroyed the aircraft, fragmenting the cockpit and cabin and resulting in a nonsurvivable environment. Likewise, the seats were fragmented and showed widespread evidence of omnidirectional loading. Primary loading on the seat legs was to the right.

1.16 Tests and Research

1.16.1 Engine Parts Trajectory Information

The parts which had been ejected in flight from the right engine and which were found on the airport were identified and their locations were plotted on an airport diagram. The identified parts included about 90 percent (by weight) of the failed right engine 9-10 high pressure compressor spacer, thirteen 9th stage and twelve 10th stage compressor rotor blades, part of the compressor stator assembly, compressor vanes, compressor vane shroud, and a small (2- by 2-inch) piece which appeared to be engine cowling. The weight of the nine spacer pieces found adjacent to runway 19R was 2.16 pounds with the largest single spacer piece weighing 1.03 pounds. The weight of the unrecovered 9-10 spacer pieces was about 0.3 pound (the difference between the total weight of an intact P/N 482178 spacer and the weight of the recovered spacer pieces). This would include any material ground away during the rupture and ejection of spacer parts from the engine.

The exit velocity and initial exit angle of ejected engine parts were assumed, based on the tangential velocity, as a result of rotational speed, spacer diameter, position of the hole in the engine, and on Pratt & Whitney experience with other ejected engine parts. Research on types of rotor failure and characteristics of fragments 19/ revealed that when a fragment is ejected from a high speed turbojet engine and passes through an engine casing, it may be deflected from its initial path. However, the research revealed that the deflection causes a loss of energy which is absorbed by the material which deflects the part. The deflection is equally likely to be in an axial or circumferential direction. (See figure 2.) The author reported that observations of damage to surroundings, which were subjected to uncontained turbine engine parts, show heavy fragments to remain within 5° of the plane of the rotor. (See figure 3.) Greater deflections have been recorded with lighter fragments, but deflections at greater angles than 33° result in the fragments losing virtually all of their energy. The report assumes that in striking the case of an engine, a fragment loses the component of velocity perpendicular to its final line of flight, a decelerating impulse induced by friction between the fragment and the casing.

Pratt & Whitney representatives testified at the public hearing that their experience had shown that the initial trajectory of uncontained rotating turbojet engine parts may be estimated by assuming that the parts (or fragments thereof) were initially ejected tangentially from their previous plane of rotation, through holes in the case and cowling. This is consistent with the aforementioned research findings. The initial trajectory path may be estimated by aligning a straight object, such as a broomstick, through the hole in the engine case from which the parts were ejected, to the outer diameter of the spacer or rotor that failed (the "broomstick" method). Pratt & Whitney reported that its previous service history of uncontained compressor spacer failures in JT8D-7 and JT8D-1 engines revealed that in incidents where the fuselage was penetrated by ejected spacer pieces, the holes in the fuselage were nearly directly in line with the penetrations of the engine case and tangent to the outer edge of the failed rotating part.

Using the broomstick method and relying on the Pratt & Whitney service experience, the initial trajectory of the ejected right engine spacer pieces was determined

19/ McCarthy, D., "Types of Rotor Failure and Characteristics of Fragments," An Assessment of Technology for Turbojet Engine Rotor Failures (Massachusetts Institute of Technology, March 29-31, 1977).

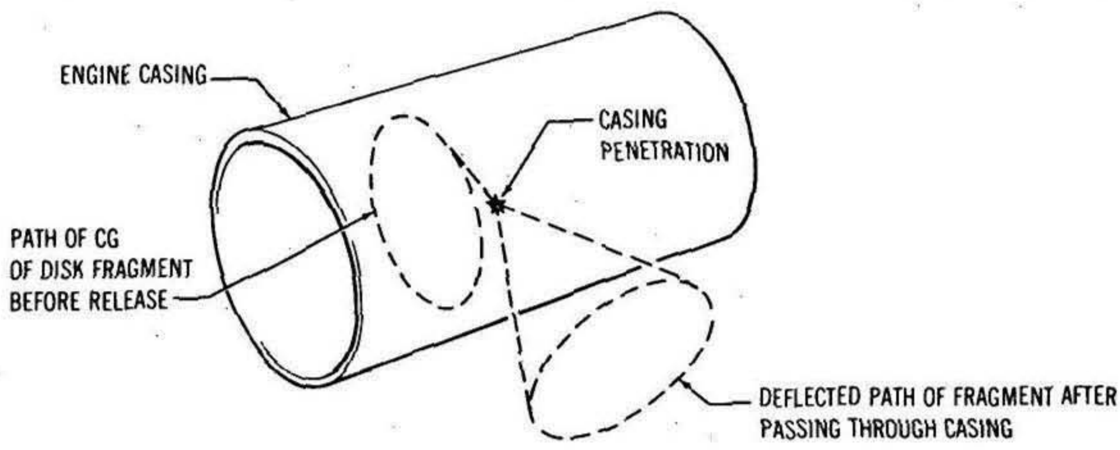


Figure 2.—Deflection path of uncontained engine parts.

to be at an angle of about 20° to the right of vertical, away from the fuselage. Based on the calculated climb performance of N100ME (50 feet per second) before the right engine failed, the pitch attitude of the aircraft was determined to be 12° nose-up at the moment of the failure. The engines of the DC-9-14 were mounted to the engine pylons at another 3° nose up. Thus, the ejected engine parts were assumed to have a rearward component, based on the rearward alignment of the engine, 15° nose-up horizontal. A wind factor, based on a wind from 220° at 17 knots, was assumed.

The recovered spacer and compressor blade parts were measured to determine drag reference areas, using a factor of 0.635 20/ to allow for tumbling of parts. Thus, the drag reference areas for the largest spacer part, weighing 1.03 pounds; a smaller spacer part, weighing 0.07 pound; and a compressor blade piece, weighing 0.035 pound were determined to be 0.138, 0.03, and 0.019 square foot, respectively. A flat plate drag coefficient of 1.0 was assumed. For the purpose of determining potential tangential velocities, initial ejection speeds between 0 and 800 feet per second (fps) were considered. (Pratt & Whitney determined that the rim tangential velocity of the operating high pressure compressor spacer had been 800 fps.)

The heaviest part would have been most sensitive to the exit velocity and angle. The lighter parts would have been more sensitive to wind factors. It was found that the predicted central point of ground impact would have been about 400 feet rearward and 200 feet left of the aircraft at the time the parts were ejected from the right engine, assuming that the parts were ejected while the airplane was about 450 feet above the ground, left of the runway centerline and at 168 knots. The calculated ejection point was consistent with the point at which parts were determined to have been ejected, based upon the timing of the "clunk" on the CVR tape; the correlation of FDR, CVR, and recorded radar data; and the locations of the recovered engine parts.

The Safety Board explored the possibility that engine parts which were not recovered might have either struck the airplane and been deflected or struck and

20/ A tumbling rectangular object presents an average frontal area of 0.635 times (the side 1 plus side 2 area).

penetrated the airplane. It was found that exit velocities would have had to be substantially reduced to 60 to 130 fps for fragments to assume trajectories which would allow them to strike the horizontal stabilizer a grazing blow at a 13° to 16° impact angle. Exit velocities required for parts to strike the vertical stabilizer near the rudder hinge line were determined to be in the order of 35 to 70 fps, resulting in an impact angle of 4° to 6°. A Pratt & Whitney engineer testified at the public hearing that his calculations revealed that if parts were deflected enough to allow them to strike the fuselage, the resultant impact would have had a perpendicular component (into the fuselage skin) of about 10 mph. A consultant for Midwest Express Airlines calculated that, for either the 1-pound spacer part or for a 0.035-pound compressor blade part to have struck the fuselage at 90 fps, it would have been necessary for the parts to have been ejected from the engine with an exit angle 65° left of vertical (85° left of the initial ejection angle).

1.16.2 Containment of Engine Parts

The research also addresses a dilemma related to engine design. That is, to contain fragmenting engine parts, engine casings strong enough to contain the highest energy fragments would be required. This, however, would require a generally unacceptable weight penalty, would create problems of thermal lag in the casings, and would substantially increase the loads on engine mounts.

The research indicates that the energy of a failed engine part, that bulges but does not rupture an engine casing, is transferred to the casing. The addition of the energy from a second part also would be transferred to the case. If the second part struck the same point, additional energy would be absorbed at that part of the case, possibly rupturing the casing. The release of multiple blades (for example) may be assumed to be released singly or in groups and the resultant impacts of those parts against the engine casing may occur almost simultaneously within a small target area. Thus, the containment or noncontainment of engine parts is dependent upon the number, size, and weight of the parts; the relative dimensions of the engine casing; and the rotational velocity of the parts.

1.16.3 JT8D Removable Sleeve Spacers

Removable sleeve high pressure compressor spacers have been used in Pratt & Whitney JT8D engines for more than 20 years. Spacers are installed at six locations within the high pressure compressor of every JT8D engine. The removable sleeve spacer consists of a spacer (similar in shape to a barrel hoop and designed to separate and align compressor disks) and 12 press-fit tubes through which tie-rods pass to align and maintain the integrity of the entire compressor. The 9-10 spacer includes two knife edges, extending from pedestals on the outer circumference of the barrel (or hoop) and which provide a rotating air seal between the spacer and the stationary seal land. (See figure 1.)

Pratt & Whitney service history has shown that rupture of the removable sleeve spacer usually results from cracks which may initiate from stress corrosion, stress alloying, and corrosion pitting of the spacer barrel adjacent to removable sleeves, and from contact between the knife edge and the stator stationary seal land. The most common crack source has been knife edge cracks that propagated through the pedestal and led to failure in the spacer barrel. Pratt & Whitney reports that friction associated with knife edge rubbing produces heat that initiates fatigue cracks in the knife edge. Many of the knife edge crack-initiated ruptures have been attributed to inadequate inspection or repair during compressor module overhaul. All of the uncontained spacer failures to date have reportedly involved the removable sleeve design.

Pratt & Whitney records revealed that 45 removable sleeve spacers had failed in JT8D engines before the September 6, 1985, Midwest Express accident. Twenty-six of the incidents resulted in the in-flight shutdown of the affected engine, and 7 incidents resulted in penetration of the cowling by ejected spacer parts. Five of the incidents which involved cowl penetration also resulted in spacer parts penetrating the fuselage. Only one case where spacer parts penetrated the fuselage involved a DC-9 airplane. Two additional failures occurred in a Pratt & Whitney test cell. None of the previous incidents resulted in loss of an aircraft or caused any injury.

In early 1980, Pratt & Whitney conducted cyclic spin testing of a 7-8 stage spacer from a JT8D engine to generate data on knife edge crack propagation rates in high pressure compressor spacers. The test was conducted at a temperature of 540° F, approximately the normal operating temperature of the spacer. The spacer was subjected to stress by repeatedly cycling from 1,000 to 12,600 rpm to simulate engine stress cycles. 21/ Four saw cuts with depths of 0.011, 0.071, 0.135, and 0.297 inch were made in the knife edge and pedestal so that propagation rates for different crack lengths could be generated simultaneously. The spacer was subjected to a total of 5,000 test cycles. Data collected from the test allowed Pratt & Whitney to study the nature of crack propagation from knife edge initiation and to predict cycles from crack to rupture in other spacers.

The cyclic spin test disclosed that a 0.010-inch long (10-mil) crack in the knife edge would typically propagate through the knife edge to the top of the pedestal (which supports the knife edge) in about 13,000 cycles. The data showed that the crack typically would progress through the cylinder wall in an additional 7,000 cycles, and then would progress axially until rupture of the spacer barrel in about 1,000 additional cycles. Thus, such a crack would progress from a 10-mil length in the knife edge to rupture of the spacer in about 21,000 cycles. According to Pratt & Whitney, before rupture, the spacer barrel may deflect into the stator seal land and frequently results in abrading away the knife edge and removing the original crack. The ruptured spacer then separates into segments, which may exit the engine.

The cyclic spin test indicated that a 10-mil crack originating in the cylinder wall typically required 25,000 cycles to become a cylinder-through-crack, and then another 1,000 cycles to rupture. (Pratt & Whitney cyclic spin test results are shown in figure 4.) In each example, a 10-mil crack was assumed as the initiating crack length.

Pratt & Whitney reported that the growth of spacer knife-edge cracks is retarded when the cracks begin to propagate into larger cross sections. The spin test showed that about 3,000 cycles are needed to progagate a knife-edge crack from the thin knife edge to the thicker pedestal section of a compressor spacer.

Based upon an analytical model developed from the 1980 cyclic spin pit data, Pratt & Whitney concluded that, at approximately 3,000 test cycles before (imminent) rupture of a 7-8 stage spacer, a fatigue crack initiating in a knife edge would have extended to a length of at least 0.20 inch. A crack of this size would extend through the knife edge and into the pedestal in either the 7-8 or 9-10 stage spacer. Pratt & Whitney calculated a crack growth rate equation for a 9-10 stage spacer based on the 7-8 stage data and the known differences in operating temperatures and stress. The calculation indicated that a knife edge crack would be 0.33 inch in length about 3,000 (test) cycles before rupture of the 9-10 stage spacer.

21/ Cycles were defined as a flight, including one takeoff and landing.

Minimum crack length detection limits are dependent on operator technique and experience, the condition of the inspection equipment and other variables. During the cyclic spin test, crack extensions of 0.040 to 0.045 inch were detected using flourescent magnetic particle inspection (FMPI). Pratt & Whitney recently gathered unrelated field data (from airlines and repair stations) on FMPI of bolt hole cracks in 10th stage disks which were composed of the same material as the spacer. These data also indicated that cracks 0.045 inch in length within the bolt holes could be detected using FMPI techniques.

1.16.4 Metallurgical Examination of Aircraft Parts

Nine pieces of the right engine 9-10 spacer, pieces of the aft fuselage and empennage skin, broken left engine eighth and ninth stage compressor blades, control cables, and the rudder pedals were examined at the Safety Board's Materials Laboratory.

Right Engine - 9-10 High Pressure Compressor Spacer.--All of the spacer pieces were heavily deformed and contained areas of rust-colored oxidation products as a result of exposure to the environment after release from the engine. The corrosion was heaviest on the inside diameter of the barrel of the spacer.

Many of the spacer piece fracture surfaces were obliterated by secondary damage. Those fracture areas not damaged were, with one exception, typical of overstress separations. The one fracture area which did not appear to be an overstress separation was found on one end of the largest spacer piece. It was on a flat axial plane through the rear knife-edge pedestal and a portion of the adjacent barrel. Near the fracture, heavy rotational wear had completely eroded the forward knife edge and pedestal, had progressed completely through the barrel between the pedestals, and had eroded a portion of the rear pedestal. Heavy corrosion deposits, which extensive cleaning could not totally remove, were found on the flat axial fracture area. However, there was a gently arcing boundary between the flat axial fracture area and a shear lip region adjacent to the inside diameter of the barrel. The flat plane of cracking in the flat axial zone and the gently arcing boundary were consistent with progressive cracking which initiated in the rear knife edge or pedestal and progressed inboard. A metallographic section through the flat axial zone revealed no evidence of branching cracks, such as those associated with liquid metal embrittlement.

Numerous small circumferentially aligned cracks were noted in various spacer pieces in the barrel, between bleed air holes. A metallographic section through one area with a signficant number of these cracks revealed that some cracks were filled with nickel. Nickel and cadmium are used to plate the parts during rework to prevent corrosion.

In many areas on the spacer, the snap surface nickel cadmium layers had debonded the underlying steel. The debonded areas could easily be extended by pulling on the already free portion of the nickel cadmium layers. A very small amount of cadmium was detected in the freshly debonded areas. No defects were found on metallographic sections through the snap surface areas which were not debonded.

Aft Fuselage and Tail Damage.--Damaged areas of skin were examined to determine whether the damage was produced by ejected right engine components. One damaged area in the vertical stabilizer had been penetrated from the inside, toward the outside of the stabilizer, indicating post-impact damage; thus, no further work was warranted on this sample. Of the remaining samples, each contained a scrape mark and some contained skin penetrations, although there was no evidence that parts had passed through the skin and entered the airplane. All of the scrape marks were consistent with an object striking at a very shallow angle to the surface of the skin and were approximately aligned horizontally in the direction of airplane motion or air flow. Trace amounts of cadmium were detected in several scrape areas; however, no evidence of nickel was found.

Tests were conducted to determine the type of metal transfer which might occur when a spacer part contacted the aluminum alloy airframe structure. Skin sections were struck against sharp 90° exterior corners of a 8-9 stage spacer section. Analysis of the contact areas revealed the presence of a significant amount of cadmium (from the nickel/cadmium surface layer on the spacer). Only a very small amount of nickel was transferred to the skin surface. The tests did not conclusively determine whether a spacer part impacting a skin area at a shallow angle, would leave behind traces of cadmium without leaving behind traces of nickel.

Therefore, the Safety Board could not determine from the metallurgical examination whether spacer parts had produced any of the observed airframe damage.

Left Engine - Eighth and Ninth Stage Compressor Blades.--Examination of broken eighth and ninth stage compressor blades revealed that many blades contained high stress fatigue cracking features over much of the fracture area. In all cases, there was evidence that fatigue cracks initiated near the blade root, from multiple origins on both the concave and convex sides of the blade airfoil section. No evidence of a preexisting defect was found in the initiation areas.

Control Cables.--The control cables from the rear of the aircraft were examined for evidence of ground impact damage or metal transfer associated with nickel cadmium-plated parts. Many of the fracture surfaces had been damaged but only one damage area contained traces of cadmium. However, the amount of cadmium was insufficient to allow the Safety Board to conclude that the cable had been struck by a cadmium-plated component because exposure of the cables to ground fire could have deposited residue with cadium concentrations comparable to that found.

Rudder Pedals.--Because of a previous history 22/ of rudder pedal support arm failures, the Safety Board examined the rudder pedal assemblies in its Materials Laboratory. The examination revealed that all portions of the rudder pedal assemblies had been subjected to heavy fire damage. Even after cleaning, the fracture areas on the captain's and the first officer's left rudder pedal support arms were partially obscured by heavy corrosion deposits and fire residue. The fractures were rough in texture, similar in appearance and had occurred at virtually the same location on the assemblies. Although no evidence of fatigue cracking was discernable, the fracture mode of the pedal support arms could not be positively determined.

1.16.5 Aircraft Performance Calculations

At the request of the Safety Board, Douglas Aircraft Company calculated the takeoff and climb performance of N100ME. The calculations were based on two engine

22/ McDonnell Douglas DC-9 Service Bulletin 27-209, issued May 29, 1981, and Airworthiness Directive (AD) 82-04-02, effective March 21, 1982, were issued to require periodic inspections of the magnesium alloy ruddder pedal support arms to detect possible fatigue cracking that had resulted in past failures of rudder pedal support arms during ground operations. Maintenance records for N100ME revealed that the inspection specified by the AD had been accomplished in August 1985 and that no cracks were detected.

climb performance to 1,130 feet m.s.l., followed by the loss of one engine and continued climb with varying degrees of thrust loss on the remaining engine. (The thrust loss from the second engine was indicated in the CVR sound spectrum examination.) The calculations revealed that if takeoff thrust had been 11,000 pounds (per engine), a loss of about 4,000 pounds thrust from the remaining (left) engine eventually would result in the pilot being unable to maintain level flight, although control of the aircraft could still be maintained. These calculations did not assume any sideslip as a result of the initiating engine failure.

The calculated initial performance of N100ME was consistent with a normal two-engine operation of a DC-9-14 airplane. The actual liftoff was determined to have occurred about 1.6 seconds beyond the optimum performance liftoff point. The calculated gear-up, stabilized two-engine climb rate was consistent with a 12° pitch attitude. Climb rate 4 seconds after the right engine failed was compatible with a normal transition to a single engine operation.

Several representative ground tracks were developed from a DC-9 aerodynamic model using equations of force, moment, and motion similar to those used in simulator models. The tracks were not representative of the result of all possible control inputs but were useful in arriving at a rough flight profile of the accident airplane. Comparison of the tracks with the radar and FDR profile of the flight provided an indication that right rudder may have been required to produce the rate of heading change which was documented by the FDR.

The Safety Board used FDR airspeed data to calculate the distance traveled. The FDR-indicated airspeed was corrected for sideslip by subtracting the airspeed error, which was determined to be zero at FDR time 00:54 (1/2 second after the engine failure) and 14 knots starting at 00:59. Corrected airspeed was then converted to true airspeed to which a wind component of 13 knots (at the runway) to 16 knots (at altitude) was applied to determine groundspeed. Groundspeed was integrated to yield distance traveled. (See appendix F.) The 14-knot error was applicable until 1:09 FDR time, which was the end of the CVR tape and the time of impact.

1.16.6 Flight Demonstration

Safety Board investigators interviewed DC-9 pilots regarding the single engine flight characteristics of the DC-9-14 airplane. McDonnell-Douglas pilots stated that the airplane had no unusual handling characteristics and that it did not require "exceptional pilot skill" during single engine flight, even with the yaw damper disengaged. They testified that the airplane was easily controllable (with control wheel input) after a sudden loss of thrust from one engine, even without the use of rudder to compensate for yawing of the aircraft. Other pilots, however, advised the Safety Board that the DC-9 was a "rudder airplane" and that prompt and correct rudder deflection was necessary for recovery from the loss of thrust, following an engine failure, particularly just after takeoff. Some pilots also advised the Safety Board that the DC-9 had unstable (undamped) yawing motion with the yaw damper off, contrary to the McDonnell-Douglas testimony.

The Safety Board learned that the available wind tunnel and flight test data were not sufficient to define the lateral dynamic response of the airplane following the sudden loss of thrust from one engine at takeoff speeds. To resolve the questions, the Safety Board conducted a flight demonstration using an FAA DC-9-14 airplane on June 11, 1986. The airplane was operated by FAA and McDonnell-Douglas test pilots who were qualified in the DC-9. Three separate procedures were used to duplicate a loss of thrust from the right engine:

(1) Slowly reducing thrust by retarding throttle and compensating for yaw with appropriate rudder deflection. (At steady flight, the rudder was quickly returned to neutral.);

(2) A rapid throttle chop beginnning at takeoff power (with no rudder input to correct for yaw); and

(3) Reduction of thrust by shutting off the fuel flow at takeoff power (with no rudder correction).

In each test, takeoff power was maintained on the left engine. The maneuvers were performed with the landing gear up, with 20° flaps, and at speeds consistent with the Midwest Express flight profile. The plan was to demonstrate a sequence of flight conditions which were considered progressively more severe. The initial demonstrations were performed at about 10,000 feet m.s.l. to allow an appropriate safety margin. Later demonstrations were conducted at about 5,000 feet to allow a greater thrust differential, more closely duplicating portions of the accident flight after it had been demonstrated (at 10,000 feet) that the airplane handling was docile. The pilots used preplanned flight test cards which outlined procedures which were practiced in the same Republic Airlines DC-9-10 visual flight simulator that was used to train the Midwest Express pilots. The flight was documented with the CVR, FDR, and a high quality audio recorder (for engine sounds) and a videotape (cockpit instruments). Rudder and control wheel deflection also were measured. Because of the docile nature of the airplane during the initial tests, only 7 of the 11 planned demonstrations were necessary to obtain meaningful data.

In the first set of demonstrations, during yawing motion (which resulted from engine-out operation), indicated altitude rose about 50 feet and the indicated airspeed rose about 3 knots. A corresponding 8° to 9° left rudder deflection was required to offset the asymmetrical thrust condition which caused the sideslip. A 25° to 30° left wheel deflection (aileron input) was required to maintain a near-wings-level attitude with the rudder neutral, although slightly greater deflections were used as the roll rate was initially arrested. (Full control wheel deflection is in excess of 90°. Full rudder deflection is about 37° at speeds below 176 knots.)

The throttle "chop" demonstrations resulted in a final yaw angle of 7° to 9° attained in about 4 seconds with the yaw damper off. With the yaw damper on, the yaw angle was reduced slightly. The engine pressure ratio had decreased to its lowest level in about 1 to 1 1/2 seconds. About 30° of control wheel deflection was required to maintain neutral roll attitude (with rudder neutral) after the throttle chop. There were no significant differences between the throttle chop demonstrations and fuel cut demonstrations.

In one series of demonstrations, the airplane's response to the absence of both aileron and rudder control input (following a simulated engine failure) was documented. With the rudder damper on or off, a 30° roll angle was reached in 7 to 8 seconds. When the pilot pushed forward slightly on the control yoke, the pitch angle dropped from 15° nose up to 10° nose down. With no control yoke movement by the pilot, the pitch attitude changed from 10° up to about 5° downward. Recovery required 90° of control wheel input for 1 second in the first case and for 3 seconds in the latter.

The results of the flight demonstration showed that at 170 knots and with the loss of thrust from the right engine:

(1) The airplane was easily controllable without the use of rudder deflection;

(2) The yaw damper had little effect on the airplane motion and was not essential for recovery;

(3) At greater thrust levels, the airplane incurred a heading change of 8° to 10° in 3 to 4 seconds; and

(4) Static pressure error due to sideslip was demonstrated and was consistent with the static pressure error data provided by the Douglas Aircraft Company.

The flight demonstration pilots reported that the airplane performance in all of the demonstrations was docile and easily controllable after a sudden loss of right engine thrust at 170 knots, even without rudder input or yaw damper action. The airplane performance, which was documented by the flight demonstration, was consistent in all respects with the applicable certification standards.

*** 1.17 Additional Information**

2. ANALYSIS

2.1 General

The examination of the events that led to the accident began with a review of witness observations in conjunction with the ATC radar and CVR and FDR data. Witnesses were consistent in their descriptions of the performance of the aircraft during the takeoff roll, rotation, liftoff, and initial climb. The observation by one DC-9 qualified pilot that the rotation to a takeoff attitude seemed abnormally abrupt was inconsistent with all other witness observations and was not corroborated by the FDR data. The aircraft performance data, subsequent to the liftoff, was consistent with normal two-engine operation and disclosed evidence that all flight controls were functioning through the period of takeoff roll, rotation, and initial climb before the right engine failure. Thus, the Safety Board concludes that there were no operational irregularities of any consequence in those phases of the flight.

Witnesses were consistent in reporting that their attention was attracted to the airplane because of one or more loud noises, described as "bangs," and similar to "shotgun reports," which occurred about the same time they saw flames and/or smoke from the right engine. The audible "bang," associated with an engine failure was confirmed by the CVR. Witnesses did not describe flame emitting from any part of the aircraft other than the right engine. Examination of the airplane confirmed that there was no in-flight fire other than that contained within the right engine. The witnesses estimated that these events occurred about 300 feet a.g.l. It was determined that the right engine actually failed about 450 feet a.g.l.

**ICAO Note.— Section 1.17 was not reproduced.*

Sixteen witnesses reported that the aircraft seemed to decelerate following the right engine failure, consistent with FDR data. The deceleration of the airplane was caused primarily by the loss of thrust from the right engine. The deceleration also was influenced by sideslip-induced drag and a reduction of left engine thrust. Reduced airspeed and increased G load made the airplane susceptible to accelerated stall. The presence of sideslip made the airplane susceptible to rolling motions.

Correlation of the FDR, CVR, and air traffic control data allowed the Safety Board to make several determinations regarding the flight. The airplane was climbing about 168 knots with a 50-foot per second rate of climb when the right engine suddenly failed. For 3 to 4 seconds, control was maintained with little change in heading, indicating that there was an initial correct (left) rudder pedal application. Accelerometer data showed a reduction of normal G loads, indicating that the airplane's pitch attitude was lowered, apparently to reduce the rate of climb and to prevent a deterioration in speed. The left rudder pedal application and reduction of the airplane's pitch attitude were consistent with the normal flight control responses following loss of thrust from the right engine of a DC-9 airplane. About 4 seconds after the right engine failed, the airplane began to yaw rapidly to the right, as indicated on the FDR data by the 20° heading change from the third to the seventh second (after the right engine failure), while the radar data indicated that the airplane was continuing in a relatively straight track. The yaw rate was greater than that which would have occurred due to a sudden loss of right engine thrust, or a sudden release of the rudder pedal force used to compensate for the asymmetrical thrust.

The Safety Board determined that the sideslip angle reached about 15° and that the total yaw reached 20° during this interval. The airplane heading deviated even farther to the right and at a more rapid rate from the eighth to the ninth second, indicating that a large roll angle was developing. As the airplane started to descend, the normal acceleration forces increased rapidly. About 1 second later, 9.6 seconds after the right engine failure, the stall warning stickshaker activated when the normal acceleration indication was 1.5 G. Normal acceleration increased to about 1.8 G while the descending right turn continued, indicating that the airplane entered an accelerated stall at about 148 knots. The airplane crashed about 5 seconds later. (See figure 5.)

The large heading changes which occurred later than the ninth second after the engine failed could not have occurred without the development of a large roll angle, in addition to right rudder deflection. Also, the ground track was not consistent with heading change due to roll angles, and the low normal accelerations (less than 1 G), which were recorded in this interval, would diminish the effects of roll angle on the heading change rate. Therefore, the Safety Board concluded that the sudden heading change which occurred before the eighth second after the right engine failure was caused by a yawing moment, rather than a rolling moment.

The Safety Board believes that the configuration of flight 105 did not change after gear retraction. The flaps probably remained at 20° deployment until impact when they were driven farther downward to about 28°. In other DC-9 accidents, the Safety Board has found similar flap movement during the impact sequence. There was no evidence that the flightcrew initiated efforts to land the airplane.

The investigation revealed that the flightcrew was medically and operationally qualified for the flight. They had received sufficient rest, and no evidence of adverse stress-related factors was found. Weather and air traffic control were not considered to be factors in the accident.

N100ME was certified, maintained, and equipped in accordance with applicable FAA regulations and approved procedures. The original airplane certification process had required demonstration of relevant handling qualities of the airplane, including conditions normally encountered in the event of sudden loss of thrust of either engine. The results of this investigation did not reveal any handling characteristics of the DC-9-14 which were inconsistent with the original standards for certification of the airplane. For example, the pilots who participated in the Safety Board's DC-9-14 flight demonstration described the airplane's handling characteristics as docile, even after the sudden and complete loss of thrust from the right engine in a simulated takeoff/climb phase of flight. Consequently, the Safety Board concludes that the loss of control of the airplane was not directly attributable to the loss of thrust from the right engine.

The analysis of this accident thus examined those factors which, in conjunction with the failure of the airplane's right engine, might have caused the pilots to lose control. Those factors included:

- The possibility that fragments of the right engine separated with sufficient energy and trajectory to cause critical damage to the airplane's flight control system;
- The possibility of control system malfunction(s) which, in combination with a single or dual power loss, could have rendered the airplane uncontrollable;
- The possibility of a mechanical failure of the left engine, either related or unrelated to the failure of the right engine, which left the airplane with insufficient thrust to maintain flight; and
- The possibility of inappropriate flightcrew response to the emergency presented by the failure of the right engine.

To resolve the factors which precipitated the loss of control, it was first necessary to examine the circumstances of the failure of the right engine.

2.2 Right Engine Failure and Secondary Damage from Uncontained Engine Parts

The physical damage to the engine and the condition of the inlet fan blades and low pressure compressor blades indicated that the right engine had little or no rotation at impact with the ground. The sound spectrum examination of the CVR-recorded engine sounds also indicated that this engine lost rpm very rapidly after the engine failure.

The hole in the high pressure compressor in the plane of rotation of the 9-10 stage removable sleeve spacer and the damage to the compressor and spacer revealed conclusively that the spacer had ruptured in flight and that the spacer parts were not contained by the engine casing. The ejected spacer parts had ruptured the rear skirt intermediate case at the 11 to 1 o'clock position, leaving a 4-by 7-inch opening in the top of the case. The loss of the spacer and consequential damage within the right engine caused a rapid deceleration and a complete loss of thrust from that engine.

The Safety Board based its analysis of the trajectory of ejected engine parts from the right engine on the following: (1) Pratt & Whitney's experience in other incidents which involved rotor and spacer uncontained failures, (2) the research described in the D.McCarthy report, (3) the physical evidence obtained in examination of the right

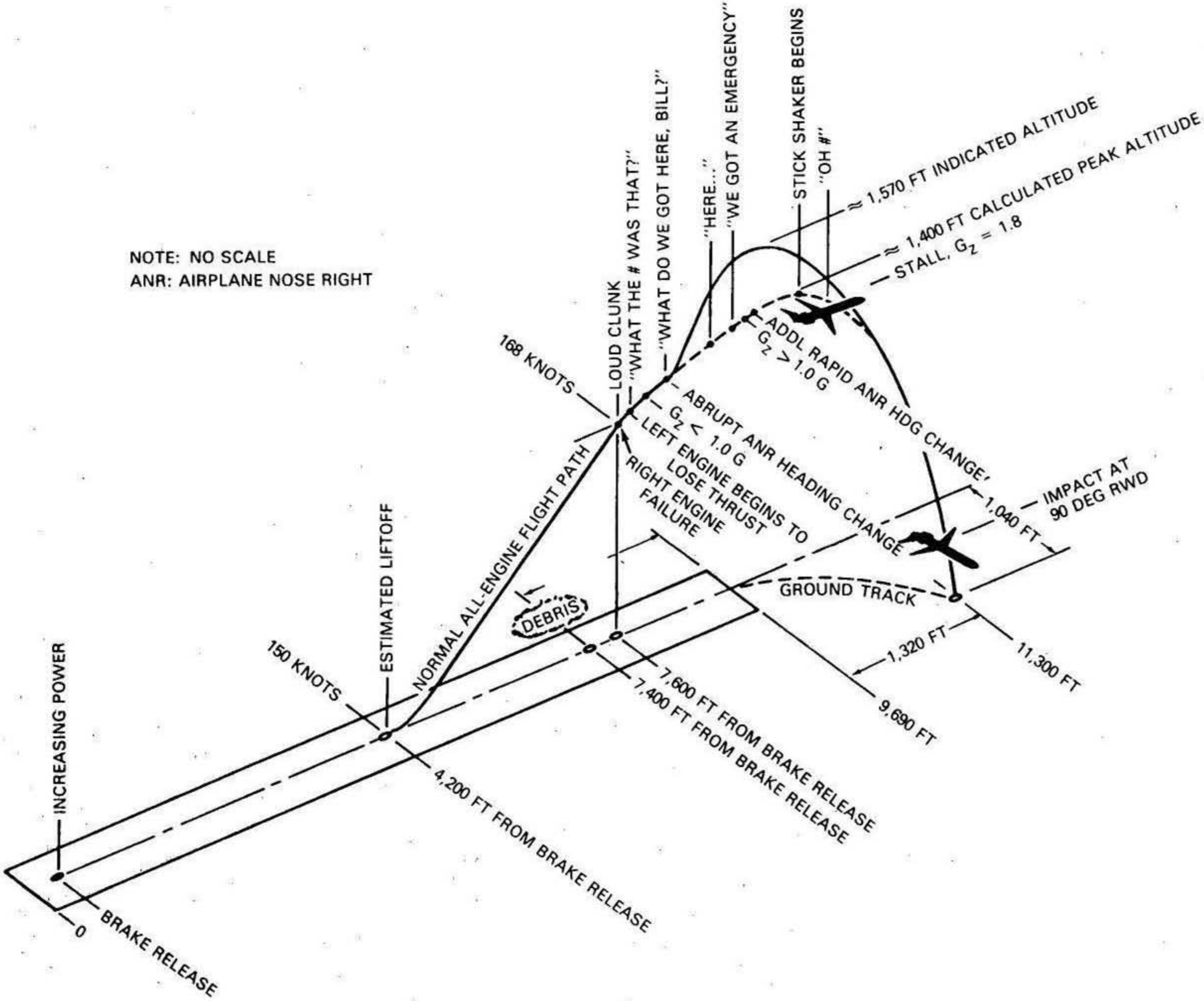


Figure 5.—Representation of the estimated flightpath and sequence of events.

engine and locations of debris at the accident site, (4) the analysis and data contained within the submissions of the parties to the Safety Board's investigation of this accident, and (5) the Safety Board's engineering analysis of the trajectory of engine parts.

Calculations showed that, from the point at which spacer parts were actually ejected from the right engine, the distribution of the parts found near runway 19R was as predicted for undeflected parts exiting the right engine. (See figure 6.) The ejection paths of a few spacer pieces and compressor blades pieces could not be resolved because those parts were not found. However, based on the paths of the recovered debris, the Safety Board concludes that part of the spacer was probably ground into tiny, harmless pieces during the rupture and that part of the unaccounted for spacer pieces and blades might have been missed, despite a thorough search for engine debris in the grass adjacent to the runway.

Calculations showed that the deflection of engine parts by the engine casing or cowling would have resulted in the absorption of energy of the deflected parts, thereby reducing the velocity substantially and limiting the potential to produce any damage of consequence to the fuselage or to the control systems. For example, engine containment tests have shown that ejected engine debris which is deflected more than 33° loses virtually all of its energy.

Figure 7 shows that undeflected parts are initially ejected in a direction approximated by the broomstick method; in this case, 20° outboard of vertical (away from the airplane fuselage) with high energy and speed. To have struck the Midwest Express fuselage, the parts would have had to have been deflected in excess of 65° and thus virtually all energy would have been lost.

Study of the DC-9-14 control system revealed that all of its components which pass through the aft fuselage pass the engines below the cabin floor level. All were protected by multiple layers of aircraft structure. Therefore, for ejected engine parts to have struck and damaged any of these control system components, the ejected parts first would have to have been deflected more than 120° from their initial tangential ejection path and then would have to have penetrated and continued through engine cowling, engine pylon, fuselage, possibly fuselage supporting structure, the cabin floor, and possibly several intercostal floor beams. Having reached the control system component(s), sufficient energy would have to have remained to disable the system components. The Safety Board believes that the possibility of ejected engine parts reaching internal control system components was extremely remote, if not impossible.

The possibility of parts penetrating the fuselage at a point farther aft and damaging control components in the vertical fin would have been even more remote. Relatively low velocities would have been required for parts to have progressed in that direction and to have struck the airplane, while high energy would have been required to penetrate the fuselage structure. Moreover, examination of the control system revealed redundancies which would have allowed the flightcrew to maintain full control of the airplane even if some control systems had been disabled. Also, it was found that the rudder hydraulic actuator, which controls rudder movement by hydraulic pressure or by transferring control input to the aerodynamic tab, showed no evidence of preimpact damage. Additionally, the rudder power shutoff valve was found with a bent control rod and discoloration, consistent with rudder hydraulic power on at ground impact.

The Safety Board also examined the possibility that the right engine cowl was blown open in flight or became distorted to such an extent that excessive drag was produced, affecting controllability of the aircraft. Although the right engine upper cowling was extensively damaged by impact forces, all four outboard latches remained latched. There was no evidence to indicate that the right cowl had opened in flight. All recovered right cowl pieces which could be positively identified were found within the impact area. Although a small (2- by 2-inch) piece of metal which resembled cowl material was found near runway 19R, it was determined that each square foot of deformed cowling would produce drag equivalent to a reduction of engine thrust by 100 pounds—a minor factor. Based upon the small hole (4- by 7-inch) found in the right engine case, the absence of other case deformation (other than impact damages), and the characteristics of typical uncontained engine pieces ejected at high velocity, the Safety Board concludes that the cowling deformation probably was small and therefore caused very little additional drag following the right engine failure.

2.3 Flight Control System Failure or Malfunction

The Safety Board considered the possibility of a flight control system failure or malfunction, unrelated to the right engine failure, that might have occurred simultaneously or nearly simultaneously with the right engine failure, and that subsequently led to the loss of control. The Safety Board does not believe that such a failure or malfunction occurred for several reasons, including those reasons cited previously regarding possible damage caused by the right engine failure. In addition, an analysis of the control movements, which would have been required (commanded or otherwise) for the airplane to have maneuvered as indicated by the FDR, revealed that:

(1) Rudder deflection to the left was required for the airplane to maintain heading for 4 seconds immediately after the right engine failure;

(2) Rudder deflection to the right was required to cause the heading change which occurred from the 4th to the 10th second after the right engine failure;

(3) Elevator control was required to cause the pitch-over and pull-up maneuvers which were documented by the FDR acceleration traces after the right engine failure; and

(4) Aileron/spoiler deflection was required for the airplane to maintain the roll attitude in the presence of large sideslip angles which were documented.

The Safety Board also considered the possibility that the captain's left rudder pedal support arm fractured after he deflected the left rudder pedal. Even though the fracture mode of the pilot's pedals could not be determined conclusively from metallurgical examination, there was no evidence that a pedal failed during a critical phase of flight. Review of CVR sounds revealed no noise or flightcrew response that could be associated with such an event. The similarity of the fractures on both the captain's and copilot's pedals suggests that they were subjected to similar forces at failure, most probably overstress at impact. Furthermore, failures of rudder pedals in past incidents occurred during braking actions while on the ground, rather than during in-flight operation because rudder control forces applied in flight produce less stress on the pedals. Finally, failure of the left rudder pedal would result in return of the rudder to a near-neutral position, and would not account for the deflection of the rudder to the right. Therefore, the Safety Board concludes that the rudder pedal support arm fractures were caused by overstress forces at impact and were not related to the cause of the accident.

In conclusion, the Safety Board determined, after examination of the wreckage, trajectory study calculations, and research into the DC-9-14 control system, that engine parts probably did not strike the aircraft after being ejected from the right engine. The Board believes that if any of the small engine parts actually struck the aircraft, no damage of any consequence would have occurred as a result of that contact. The Board found that there was no basis upon which to conclude that flight control systems malfunctioned or were damaged in flight, secondary to the right engine failure, and that all of the onboard flight control systems on N100ME were available to the flightcrew following the abrupt loss of right engine power.

Further, electrical power was available to the crew of flight 105 until impact based upon the continuous operation of the FDR and the CVR and the elongation of the right wingtip navigation light bulb filament, which indicated that the filament was hot and, therefore, on when subjected to impact forces.

2.4 Left Engine Power Loss

The Safety Board does not believe that the left engine power loss was significant with respect to the eventual loss of control of the airplane. Any reduction in left engine thrust that occurred before stickshaker would have reduced the yawing of the airplane which occurred after the right engine failure. While possibly necessitating a forced landing, a left engine power loss should not have precipitated, or even contributed to, a loss of control of the airplane. However, the reduction in left engine power could have confused the crew. A detailed discussion of the Safety Board's analysis of the left engine mechanical condition and operation is contained in appendix I.

2.5 Evaluation of Flightcrew Response

The flight demonstration of a DC-9-14 airplane showed that with a sudden loss of right engine thrust at 170 knots, lateral and directional control could be maintained even if the pilot took no immediate action to deflect the rudder. Under these conditions, the airplane experienced about an 8° heading change and developed about 5° of sideslip within 4 seconds. About 30° of control wheel deflection, or 8° left deflection of the rudder, was required to maintain a wings-level attitude of the airplane. The flight demonstration was conducted with about 9,500 pounds of continuous thrust on the left engine (in-flight takeoff power).

The sound spectrum examination disclosed that, on the accident airplane, the left engine thrust dropped from 10,750 pound (initially) to about 9,500 pounds after 2 to 3 seconds and to 5,500 pounds at the time of the loss of control. Because of the reduced asymmetric thrust, the yawing moment would have been reduced considerably on the accident airplane, similar to the demonstration airplane. Since there was no difficulty in compensating for the thrust asymmetry on the demonstration flight, the Safety Board concludes that the yawing moment should have been controllable in the accident airplane.

Since the airplane maintained its heading for the first 3 to 4 seconds after the right engine failed, it was concluded that the rudder was deflected properly to the left during that interval. However, based upon calculations of the airplane's yawing response and resultant ground track for various rudder deflections and roll angles, the Safety Board determined that the large heading change and sideslip angle that developed after the first 4 seconds could not have been accomplished without a deflection of the rudder to the right, followed by a roll to the right 4 to 5 seconds later.

Based upon the known performance of a DC-9-14, the closest duplication of the heading change which occurred on the accident flight (indicated by the FDR) would require the rudder to be deflected 6° to the left for about 3 seconds, followed by a rapid return of the rudder to neutral, then deflection of the rudder 12° to the right about 5 seconds after the right engine failure. Returning the rudder to neutral and holding neutral rudder, after initially applying rudder to correct for differential engine thrust, would not have created the heading change rates which were indicated by the FDR data. Likewise, a system malfunction which would cause the rudder to trail in a near-neutral position would be inconsistent with the FDR-indicated heading change data.

The demonstration flight in a DC-9-14 airplane showed that the airplane had no control characteristics which were inconsistent with the applicable certification standards; the airplane was found to be fully controllable in an engine-out flight environment, even without using rudder (the primary control for correcting yaw and maintaining heading) to correct for yaw. Having found no evidence or airplane performance basis for concluding that there was a control system failure or malfunction, the Safety Board concludes that the rudder deflection, which occurred beginning 4 to 5 seconds after the right engine failure, was the result of the flightcrew's improper response. Based on the analysis of the airplane performance, the yaw generated by the incorrect rudder deflection, combined with G loading, caused the airplane to enter an accelerated stall at an altitude too low for recovery.

In the seconds which preceded the accelerated stall and loss of control, the airplane was in a very dynamic situation. The increasing rate of roll, the sideslip, and the increase in acceleration load all affected adversely the stall speed. Because of the rapidly changing attitude of the airplane, the pilots would not have been expected to know the speed at which the airplane would stall in accelerated flight. Compared to the increase in stall speed, the 8-knot error in indicated airspeed (due to static source error in a sideslip) would not have been significant. Further, the stickshaker stall warning system would not and did not provide the customary 4 to 5 seconds warning which is typical of that system because of the rapid entry into the stall. The Safety Board concludes that the stall occurred because the flightcrew did not diagnose the nature of the emergency correctly, applied incorrect rudder control about 4 to 5 seconds after the right engine failure, and applied nose-up elevator control which increased the G loads. The nose-up elevator control input would have been a normal response to correct for the pitch-over maneuver and the reduction in pitch attitude which was precipitated by the rudder pedal induced roll and was consistent with the rapid deceleration of the airplane. The rapid deceleration would have resulted in a vestibular perception of downward pitching of the nose of the airplane.

The Safety Board believes that more effective scanning of the flight and engine instruments by the pilots of flight 105 would have enabled them to maintain control of the airplane and to properly evaluate the powerplant anomalies. The failure of the first officer to respond to the captain's questions and the failure of the captain to maintain control of the airplane suggests that there was a breakdown in instrument scan by both pilots in the critical seconds which followed the right engine failure.

In view of the finding that the loss of control of the airplane probably was caused by the flightcrew's improper response to the engine out emergency, the Safety Board examined several factors which could have contributed to the flightcrew's improper actions.

2.5.1 Flightcrew Training and DC-9 Qualification

Airlines larger than Midwest Express, with many more years of operating experience and larger pilot populations, upgrade pilots to captain based on demonstrated ability to accept the responsibilities of the position, sufficient seniority to successfully bid on the position, and completion of the required training. Midwest Express uses the same criteria; however, with a smaller pilot population, advancement to captain can occur much sooner, as indicated by the advancement of the flight 105 pilots. Pilots at the more established airlines must have a great deal more seniority and thus have more pilot experience in turbojet airplanes before captain upgrade because of the relatively slow growth of those airlines. Because of the DC-9s relatively small size in their fleets, it is typically the first turbojet airplane in which many airline pilots upgrade to captain. Based on a sampling of recent upgrades to captain at two airlines, which the Safety Board believes are representative of carriers providing most of the scheduled passenger service in the United States, the Board determined that, by comparison, both pilots of flight 105 were relatively inexperienced in turbojet operations. For example, the experience level of recent DC-9 captain upgrades at the two airlines was: in excess of 10 years' seniority with the company, in excess of 10,000 hours total pilot experience including more than 7,500 turbojet hours as first officer, and generally served as a flight engineer for more than 3 years before upgrading to first officer. The Safety Board does not believe that much experience is essential for initial upgrade to captain of a DC-9; however, extra experience does provides a greater margin of safety to the traveling public.

By contrast, the captain of flight 105 had been employed by Midwest Express for 12 months and had 600 hours of turbojet experience as a DC-9 first officer (no flight engineer experience) at the time of his captain upgrade. He had no turbojet or sweptwing airplane experience before being hired by Midwest Express. The first officer of flight 105 had previous turbojet experience in the U.S. Air Force before his Midwest Express employment. He was upgraded to DC-9 captain with only 500 hours experience in the airplane.

Both flightcrew members received training that was in accordance with FAA regulations. The first officer, who had received DC-9 instruction from USAir as well as Republic Airlines, was described by instructors of both carriers, independently of each other, as an excellent pilot. Republic Airlines' officials were pleased with the attitude of Midwest Express in that it willingly encouraged Republic to provide all the training Republic believed necessary, within reason, to train its pilots to proficiency.

The Safety Board concludes that the training that the crew received met all applicable standards. Training to proficiency, a practice used by Midwest Express, is a sound educational practice used in many professions. However, the Board is concerned about Midwest Express utilizing a "silent cockpit" philosophy which was not outlined in its approved training and operations manuals and which is contrary to other procedures which are published in approved manuals. The Safety Board believes this conflict may have resulted in less crew communication and coordination than otherwise might have been demonstated.

The Safety Board is aware that pilots with substantial experience in multiengine airplanes usually have received considerable training in engine-out emergencies and have had opportunities to practice appropriate emergency responses during initial and recurrent training. Several pilots confirmed these facts in their testimony at the public hearing on this accident and stated that a pilot's reaction, in applying proper rudder pedal forces in response to an engine-out emergency, can become reflexive because of that training and previous pilot experience.

Also, the Safety Board is aware that pilots have occasionally misidentified a failed engine in previous accidents and incidents and have erroneously shut down still operative engines. In the course of this investigation, the Safety Board learned of several simulated engine failure incidents in which pilots responded initially with deflection of the incorrect rudder pedal in the DC-9 airplane. A Douglas test pilot, who had flight instructor experience in the DC-9, testified to a personal experience where a pilot who was receiving DC-9 instruction commanded rudder deflection in the wrong direction in response to a simulated engine failure. An FAA DC-9 instructor, with extensive training experience, testified that about 1 of every 50 of his students, each of whom held an airline transport pilot certificate, had attempted to deflect the wrong rudder pedal during simulated engine failures on takeoff. The Safety Board attempted to identify other DC-9 engine failure incidents which occurred after takeoff, while at low altitude, and found that such incidents have been infrequent in this critical flight regime.

The Safety Board also found that the majority of engine-out training provided to Midwest Express pilots in the takeoff regime occurred near V1 when the simulated airplane's pitch attitude was low, which provided outside visual references, including a runway centerline which were not available to the pilots of flight 105. There was very little exposure in training to the potential errors which might occur in response to an engine failure after gear retraction in the climb phase when the airplane's pitch attitude is near 12° nose up. In this accident, with only a clear blue sky visible through the windshield, the flightcrew would not have had the outside visual references that were available during most of their emergency training. Consequently, a clear, blue sky would not have provided lateral motion cues related to sudden yaw or the roll reference that were available during V1 engine out training in the simulator.

Recognition and response to engine failures are stressed in pilot training and certification programs. Airline pilots are required to demonstrate their proficiency in these skills during initial and recurrent flight checks. The Safety Board closely examined aspects of the training in recognition and response to engine failure to determine if some aspect of the training could account for the crew's failure to respond appropriately to the emergency.

2.5.2 Engine Failure Recognition and Response

Several facts emerge when considering the influence of pilot training in response to engine failure. First, engine failures have become highly improbable events since the advent of modern, reliable turbojet engines in air transport operations. When reciprocating engines were widely used, it was not unusual for experienced pilots to encounter an engine failure in flight. Today, the opposite is true. Second, the criticality of response to engine failure is directly related to the particular phase of flight in which it occurs. When the airplane is closest to the ground, it is obvious that proper response to the failure must be immediate because time available to make decisions and to execute procedures is limited. At the same time, an airplane's airspeed is low (and closer to stall) when it is close to the ground. Thus, in takeoff or landing phases of flight, response to an engine failure must be immediate and appropriate. In other phases of flight, where delayed recognition or an improper response to an engine failure could result only in the loss of altitude and/or airspeed, a margin for error is available that is not available on takeoff or landing. Third, a failure in a turbojet engine does not always result in an abrupt (occurring in less than 0.5 second) loss of power.

Abrupt failures, such as that experienced by flight 105, are rare occurrences within a category of events that is itself unusual. While pilots are trained to recognize and respond to engine failures, the training is not generally in response to an abrupt loss of power. When pilots practice recognition and response to engine failure in an airplane, particularly at low altitude, to do other than retard the throttle to flight idle to simulate an engine failure (where residual thrust is still generated) can seriously compromise flight safety. Thus, it is necessary to conduct such training in flight simulators which do not respond exactly as the airplane, following an abrupt loss of power. However, pilot response to the engine failure should be the same regardless of the cause of the failure even though the cues which the pilot perceives may vary depending on the characteristics of the failure.

Consequently, although a pilot's response to engine failure in a twin engine airplane should be invariant, that is, the pilot must fly the airplane safely maintaining directional control through the use of rudder primarily and aileron to a lesser extent, the recognition and resultant speed of the response may be affected by the interaction of the type of failure experienced and the phase of flight in which it is encountered.

The Midwest Express chief pilot testified that the philosophy of engine failure procedures and crew response to those procedures is based upon the criticality of the situation. He stated that Midwest Express pilots are allowed more latitude, in terms of their reaction, in responding to engine failures that occur in less critical phases of flight. He categorized an engine failure on takeoff before gear retraction, for example, as being more critical than an engine failure later in the takeoff climb. This viewpoint is consistent with the pilot certification requirements stated in the Federal Aviation Regulations, and it is consistent with the general practice of the airline industry. However, underlying this approach may be an implication that failures that occur beyond V1, where immediacy of response may not be as critical, might actually encourage a delayed crew response to the failure. Thus, the Board studied the possibility that a perceived lack of criticality in the speed of the response to an engine failure after gear retraction may have led the crew to delay coordination of corrective action in response to the engine failure.

Human factors research involving operators of automobile simulators 28/ has shown that reaction time was related to the nature of the stimulus: the more simple and intense the stimulus, the faster the reaction time. Regardless of the factors involved, reaction time was generally measured in fractions of a second. Reaction time to complex stimuli generally required less than 1 second.

The captain's initial reaction to the right engine failure sound was about 1 second, as indicated by his first question to the first officer. The response time to apply correct rudder was about 1 to 2 seconds, based upon the FDR data.

The Safety Board believes that the captain's prompt rudder application was a spontaneous reaction to his kinesthetic cues and was merely an attempt to restore a balanced flight condition. As such, it probably was initiated before he had time to analyze the nature of the emergency. However, following this initial compensatory reaction, the captain, possibly as a result of other kinesthetic and/or visual cues, initiated actions that subsequently resulted in loss of control of the airplane. Because of these improper actions following an in-flight engine failure, and the apparent incorrect

28/ Wierwille, W.W., Cassali, J.G., and Repa, B.S., Driver steering reaction time to abrupt-onset crosswinds, as measured in a moving base driving simulator. Human Factors, 1983.

interpretation of available cues that prompted them, the Safety Board examined the flight simulator which was used to train the flightcrew of flight 105 to evaluate what effect, if any, that it may have had on pilot ability to recognize the engine failure.

2.5.3 Flight Simulator Training Effectiveness

Much of the Midwest Express required flight training was performed in an approved, 3 dof visual flight simulator. The differences between the simulator and the airplane cockpit layout were minor and were addressed in training. The Safety Board found that visual flight simulators have limitations in reproducing the engine failure emergency as it would be experienced in an airplane since peripheral visual cues, certain onset motion cues, and aural cues were absent in the simulator. This characteristic was not unique to the Republic Airlines simulator but was common to all visual flight simulators.

A human performance expert testified at the Safety Board's public hearing that motion cues were important in training because, without them, the training was not sufficiently realistic and might not prepare the pilot for an actual failure in the airplane. He described the (onset) motion cues which the airplane provided that were unlike those to which the pilots were exposed in simulator training. He said that the absence of those cues in training might cause confusion for a pilot when the cues were experienced in the airplane and that, thus, the pilot(s) might be prompted to make an improper response. However, DC-9 pilots who had experienced dynamic engine thrust reductions in both the simulator and the airplane stated that they did not believe the differences to be significant. Their views were generally supported by the DC-9-14 flight demonstration which showed that the lateral accelerations and yawing motions produced in flight were neither violent nor dramatic.

Because high fidelity flight simulators are a relatively recent development in the training of air transport pilots, applicable behavioral science literature is not consistent on the effects of lower fidelity simulators in pilot recognition of various in-flight phenomena. More important, the large variance in the experience of pilots used as subjects in the research limits the generalizability of the research findings in flight simulator effectiveness in pilot training. For example, the Safety Board cannot conclude that findings based on research involving low time pilots may be generalized to high time pilots. When variables, such as airplane craft complexity and number of engines, are introduced, the generalizability of the research results is reduced still further. Moreover, in air transport pilot training, there is little empirical data that researchers can use to develop conclusions about the importance of specific simulator features on pilot performance. Often, the data that are presented are of limited applicability due to flaws in the experimental design.

Because of the lack of consistency in the behavioral science research on simulator motion, the Safety Board cannot attribute the failures in the performance of the pilots of flight 105 to the lack of high fidelity yaw motion cues in the DC-9-10 visual simulator. While the simulator lacks the immediate kinesthetic yaw motion cues from thrust asymmetry in the airplane, it does replicate the long term lateral acceleration motion cues resulting from an engine failure so that the cues which are presented are similar to the airplane response. Although the pilots of flight 105 may not have experienced the exact kinesthetic and visual cues in their simulator training, the Safety Board believes that they should have been able to recognize and analyze the emergency based on the cues which were present.

However, the Safety Board cannot disregard the possibility that the type of training given in the simulator, rather than the limitations of cues provided in the simulator, could have been a factor in the flightcrew's performance. In particular, the Safety Board is concerned that the takeoff engine failure training involving a loss of thrust as the airplane approaches or passes V1 speed may have been a factor.

In a yawing condition, visual stimuli, which typically produce relatively slower reaction times than aural or kinesthetic stimuli, may enhance the perception of yaw since the pilot normally could see the nose of the aircraft moving sideways relative to objects in his field of view.

In the V1 engine failure, external visual information alone is generally sufficient to inform the pilot of the occurrence, since the airplane is either on, or only slightly above, the runway and the movement of the nose of the airplane, relative to the runway centerline, provides adequate information that an engine has failed. As a result, training in recovery from engine failure at or just after V1 might lead pilots to rely extensively on forward external visual cues, even if peripheral visual cues are present. If the peripheral information is absent, as it is in the simulator, then repeated training in V1 failures in the simulator can result in exclusive use by the pilots of visual information that is presented straight ahead, outside the cockpit.

In this accident, there were no forward external visual references since the sky was clear. At the time the engine failed, the airplane would have been in a nose up attitude of about 12° and the pilots would have been looking at the sky, if they were looking outside the cockpit. In the absence of clouds, there would have been no visual cues straight ahead that could have provided the pilots with the information needed to perceive the airplane's immediate yaw to the right following failure of the right engine. Consequently, the only external visual cues indicating a yaw that would have been available to the pilots would have been ground-based information that was presented peripherally, or the flight instruments. However, peripheral visual cues are of relatively little use for the detection of airplane yaw because the angular rates of stimuli in the periphery are generally too low to be readily apparent.

The Safety Board does not consider the limitations of the visual 3 dof simulator to have been a factor affecting the flightcrew's recognition of the engine failure since pilot training, in general, stresses to pilots the importance of confirming engine and flight control status through the interpretation of cockpit instruments. The simulator is fully adequate in the presentation of these instruments. The training records of the flightcrew of flight 105, as well as the statements and testimony of their instructor, indicated that they were so instructed. Thus, the engine instruments should have confirmed the engine failure, and the flight instruments should have confirmed the airplane's attitude, airspeed, altitude, and heading.

Nevertheless, the questions asked by the captain and his failure to maintain control of the airplane confirm that he did not correctly interpret the sounds, motion, and other available information. Therefore, the Safety Board believes that the captain reacted primarily to other than visual and flight instrument references, such as kinesthetic cues. He apparently misinterpreted those cues and applied the flight controls incorrectly. This confusion is commonly referred to as "spatial disorientation," and it occurs most frequently at night or in instrument meteorological conditions when few, if any, exernal visual references exist. Spatial disorientation causes confusion, such as that experienced by the pilots of flight 105, and would account for their incorrect control responses. The only means to prevent such confusion, or to overcome its effects, is for the pilot to rely on the flight instruments.

Therefore, the Safety Board concludes that infrequent training for an engine failure at low altitude in the initial climb phase of flight could have left the flightcrew ill-prepared to cope with the emergency. Although analyzing abnormal or emergency situations and maintaining control of the airplane by reference to flight instruments are basic elements of airmanship, the Safety Board believes that the FAA and the airline industry should consider the circumstances of this accident with a view toward including scenarios of engine failures after establishment of the takeoff climb in training programs to better prepare pilots for such emergencies. Consideration also should be given to reducing pilot reliance on external visual cues during "V1 cut" training by making greater use of simulated low visibility situations during such training.

2.5.4 Crew Coordination

The CVR comments suggest that the captain was uncertain and perhaps confused by the events which immediately followed the failure of the right engine. He had never experienced an in-flight engine failure on a DC-9, and he had not heard the sounds associated with such a failure in his flight simulator training. The yaw and deceleration motion cues he felt in the airplane also would have been slightly different from the ones to which he had been exposed in his simulator training. His first question to the first officer ("What the # was that?"), may have been rhetorical; however, the Board believes that the captain was requesting assistance. His second question ("What do we got here, Bill"?), occurred 3 seconds after the right engine failure and affirms the concern and uncertainty expressed in his first question. The quality of the CVR recording, both in volume and clarity, leaves little doubt that the first officer heard the captain.

FAA-approved Midwest Express procedures indicate that the first officer should have responded, if able, to the captain's questions because an emergency condition existed and all crewmembers were required to bring to the attention of the pilot-in-command any occurrence which might affect the safety of flight. If the first officer recognized the nature of the emergency, he should have responded to the captain's request for information. Failing to respond may have further confused the captain and that confusion apparently precipitated an improper control response when the airplane was in a critical phase of flight.

The less explicit and unwritten "silent cockpit" philosophy (not making unnecessary callouts or even verbalizing the nature of an emergency after 100 knots and before reaching 800 feet on takeoff) may have influenced the first officer not to respond. However, the Safety Board believes it is more probable that the first officer also was confused by the indications he observed and heard following the engine failure. Nevertheless, the Board is concerned about the contradiction in written and verbal policy at Midwest Express which may have resulted in poor coordination between the two pilots aboard flight 105.

Analysis of the flight track and FDR information reveals that a left deflection of the rudder was commanded properly, and, perhaps reflexively in response to a perceived heading change or yaw. However, the captain still asked his first officer what was the nature of the occurrence after correct rudder pedal pressure had been applied. Therefore, the captain reflected uncertainty and perhaps confusion after the correct rudder pedal pressure had been applied. Consequently, there was a delay in making a coordinated response to the engine failure, and the captain was uncertain that he had responded correctly. The captain's uncertainty, combined with the failure of the first officer to respond to potentially confusing engine instrument indications, and the absence of outside visual reference may have prompted the captain to remove the force from the left rudder pedal and to introduce forces to the right rudder pedal a few seconds later.

The captain may have asked the first officer for assistance, in part, because of the seniority of the first officer to the captain and because of the first officer's check airman status. The captain would have been justified in expecting that a check airman might be more knowledgeable or more capable than himself in identifying the nature of the problem. The first officer's response to Milwaukee Tower 8 seconds after the right engine failure, which was in conflict with the "silent cockpit" philosophy, was provided in lieu of responding to the captain's questions and occurred when the airplane was yawing to the right, was in a sideslip, and was on the verge of a loss of control. Callouts of memory items from the emergency check list would have been appropriate in response to the engine failure, and also would have been important if a dual engine failure was perceived. If either pilot had initiated the emergency checklist, the nature of the emergency might have been made immediately clear to the other pilot and coordinated crew response might have followed. Also, if a dual engine failure was perceived, a callout to that effect was required by Midwest Express procedures.

A possible explanation for a delay in recognizing the problem is that, instead of coordinating their actions, the captain and the first officer both had shifted to an outside scan to look for other traffic after gear retraction and neither was monitoring flight instruments at the moment of right engine failure. Another possible explanation related to instrument scanning is that the flightcrew shifted their attention collectively to the engine instruments and were not monitoring flight instruments for several crucial seconds between the time correct rudder was initially applied and the time of stickshaker activation. About 6 seconds after the engine failed, the captain said " Here . . ." but was interrupted by the first officer's response to Milwaukee Tower. The captain may have been pointing out instrument indications associated with the right engine failure, or instrument indications relevant to the left engine power loss, and he may not have been monitoring flight instruments during the brief but critical period.

It is possible that the captain (or the first officer) reacted to the left engine instrument movement. When the right engine failed, the right engine instruments probably reached a steady state condition in a very short time compared to the left engine instruments which decelerated more slowly. The Safety Board considered it plausible that the pilot's attention may have been directed to the movement of the left engine instruments after the right engine instruments became static. If he perceived that the left engine was the problem, he may have reacted to that perception by applying the rudder correction for a left engine failure rather than continuing with the rudder deflection appropriate for a right engine failure.

The attentiveness of the crew to flight instruments during the emergency and a coordinated response to the indications were critical to maintaining control because a swept wing airplane, such as the DC-9, when in a sideslip, will tend to roll unless corrective action is taken. Either the sideslip must be reduced by appropriate rudder deflection or the lateral controls must be deflected to counter the rolling tendencies. The rolling tendency due to sideslip will increase as the lift on the wings increases. For a given G load (lift) and sideslip angle, a certain amount of lateral control deflection will be required to counter the roll. As the G load increases, additional lateral control deflection will be required to counter the roll. In this case, elevator control input caused the G load to increase from about 0.3 Gs to about 1.8. Gs from the 5th to the 11th second.

In the presence of the sideslip angle and increasing acceleration load, the lateral control deflection would have to be approximately doubled to maintain a constant bank angle. If the pilot established a lateral control deflection at the fourth to fifth second to compensate for the sideslip angle and then was not monitoring the roll attitude as the G load increased, the airplane would roll further to the right. The data indicate that by the time the stickshaker came on, the airplane was in a significant roll attitude to the right and the positive G load was increasing. All of the above conditions should have been evident to the flightcrew by reference to the flight instruments.

The captain had the individual ability and the responsibility to scan the instruments and to take corrective action. However, an appropriate coordinated flightcrew response also would involve actions by the first officer to assist the captain in diagnosing and responding to the problem. The redundancy provided by the first officer is one of the basic tenets of cockpit resource management.

2.5.5 Cockpit Resource Management

The investigation revealed that Midwest Express did not have a formal training program in cockpit resource management, which is also known as crew coordination. However, the Safety Board believes that with a low pilot to supervisor ratio, the airline could, and probably did, monitor closely the performance of its crewmembers, both as pilots and as individuals participating in the joint operation of flights. Thus, the airline would have been able to assess, to some degree, the extent to which its flightcrew members were effective in working together with other pilots to manage and operate the aircraft effectively.

The Safety Board believes that cockpit resource management is of critical importance to air safety and has urged the FAA to implement formal programs to improve flightcrew coordination. As a result of its investigation of an accident involving a charter flight in Reno, Nevada, 29/ the Board recommended that the FAA:

A-86-19

Provide, to all operators, guidance on topics and training in cockpit resource management so that operators can provide such training to their flightcrew members, until such time as the FAA's formal study of the topic is completed.

In its August 25, 1986, response, the FAA indicated concurrence with the recommendation. The FAA reported that they are disseminating information to air carriers that addresses coordination and procedural interaction among pilot crewmembers. Several air carrier operations bulletins and FAA Order 8430.6C, the Air Carrier Operations Inspectors Handbook, contain guidance to FAA personnel in implementing crew coordination. The FAA acknowledged that cockpit resource management included not only procedural interaction between crewmembers, but also subtle and intangible interaction as well. The FAA has contracted with the Aviation Psychology Laboratory of Ohio State University to provide a formal study, of the subtle and intangible interaction aspects of cockpit resource management. The study is scheduled for completion in November 1987. The FAA reported that the anticipated study would serve as a foundation for a future advisory circular and would be a model for industry use. Pending the results of the FAA study, the Safety Board has classified the recommendation as "Open--Acceptable Action."

29/ Aircraft Accident Report--"Galaxy Airlines, Inc., Lockheed Electra L-188C, N5532, Reno, Nevada, January 21, 1985" (NTSB/AAR-86/01).

The Safety Board is a strong advocate of formalized cockpit resource management training. However, the Safety Board is aware that few operators at this time are conducting formal, in-depth training in cockpit resource management techniques and that the FAA has not, as yet, made this a requirement for operators. Midwest Express did not violate FAA rules or practices by not conducting formal training on the subject.

The Safety Board believes that training in emergency procedures should be so thoroughly indoctrinated in training that crew reaction should be prompt and reflexive after an engine failure emergency has been accurately identified. The actions of the flying pilot, in response to the emergency, should be closely monitored by the nonflying pilot, and the nonflying pilot should be monitoring instruments in support of the flying pilot to ensure prompt and correct response, in accordance with published emergency procedures. Takeoff emergencies typically are critical operations because of low altitude and low speed at their outset. Even though the initial response of the flying pilot may be reflexive, involvement by the nonflying pilot is essential to a proper crew response to the emergency.

In this accident, the cockpit voice recorder revealed the absence of emergency callouts from either pilot and no response from the first officer when the captain requested assistance. Because the first officer responded to Milwaukee Tower, it is clear that he was not incapacitated. However, his failure to communicate with the captain and his possible misjudgment of the seriousness of the situation may have led to an uncoordinated crew response to the emergency. The Safety Board believes that a breakdown in crew coordination was a significant factor in the accident.

2.6 FAA Surveillance and Oversight

2.6.1 Midwest Express Airlines

The Safety Board believes that the FAA oversight of Midwest Express procedures and training during certification and ongoing day-to-day activity in the carrier's first 2 years of operation was less than optimum and probably suffered as a direct result of the inexperience of the POI. The POI testified that she devoted only 20 percent of her worktime to Midwest Express, her only FAR 121 scheduled passenger airline, and that she was still obligated to perform routine general aviation duties. The Board noted that the POI had no previous FAR 121 air carrier experience, that she was not rated in a turbojet of the category and class used by the airline, and that she had not received any formal training in the DC-9 airplane used by the certificate holder for which she was responsible. In fact, she had no turbojet pilot experience. Neither did the POI have available for consultation or assistance air carrier inspectors or DC-9 rated pilots in her own office. Although the POI used the services of air carrier inspectors assigned to other offices to fulfill her responsibilities, it is apparent that this practice reduced her exposure to the operation of the airline. Apparently, she had become so dependent on other inspectors in surveilling Midwest Express that her own role was reduced primarily to administrative matters. The absence of first-hand knowledge of the carrier and her lack of experience in turbojet air carrier operations severely handicapped her ability to perform the quality of surveillence required to detect shortcomings of a FAR 121 airline operation. The Safety Board believes that the experience level of the POI was inappropriate for her assignment as the POI of a new air carrier operating turbojet equipment. She even testified that she was not totally comfortable with the arrangement.

The Safety Board also is concerned that the POI's lack of proper experience may have been a factor which allowed a "silent cockpit" concept to be taught in training even though it was contrary to the approved practice that required any crewmember noting a potential or actual emergency situation to call it to the captain's attention. The Safety Board believes that the latter concept is sound and assures that all flight crewmembers are provided the opportunity to coordinate their activities, to assure the proper resolution of an emergency condition consistent with the practices of most operators of turbojet equipment. Midwest Express employees had discussed the silent cockpit concept with the POI but had not put it in writing or requested her approval of the concept. The Safety Board believes that if the POI had been more experienced she might have recognized the flaws in such a concept, and perhaps she might have recognized that the airline was already teaching the concept in their pilot training program.

The Safety Board supports the latest efforts of the FAA through Project SAFE (Safety Activity Functional Evaluation) to alleviate substandard surveillance of the airline industry. SAFE will revise the position description and qualification criteria for prospective air carrier inspector personnel to insure that the ability of the inspector personnel who would be assigned to a FAR 121 certificate holder matches the job requirements. The FAA targets its implementation of this plan for fiscal year 1988. The Safety Board believes that the FAA should, as an interim measure, discontinue the practice of assigning FAR 121 air carrier operating certificates to POIs without the training and experience commensurate with the POI role and without a type rating in a comparable (i.e., turbojet powered transport category) aircraft in the category and class used by the certificate holder. The Safety Board noted that the Midwest Express certificate was reassigned to the Air Carrier District Office in Chicago, Illinois, following the Safety Board's public hearing. The Safety Board trusts that if the FAA has not already done so, a review will be undertaken to require that all FAR 121 certificates are overseen by FAA personnel thoroughly knowledgeable in FAR 121 operations.

2.6.2. AeroThrust Corporation

The Safety Board found that Pratt & Whitney's visits to AeroThrust revealed a number of deficiencies, many of which were not necessarily safety-related, but were related to plant efficiency. Many of the deficiencies, including safety-related items, such as improper test equipment calibration, reportedly were promptly corrected. Also, the training records for the inspector who had last inspected the right engine 9-10 spacer did not reveal the manner in which the inspector was qualified to operate the inspection equipment. Neither did they reflect the results of the inspector's required annual eye examinations. FAA surveillance had not detected the test equipment calibration deficiencies, training record deficiencies, or the apparent lack of required vision testing of AeroThrust inspectors.

The right engine fractured spacer pieces, which were examined in the Safety Board Materials Laboratory, revealed cracks between bleed air holes which contained nickel deposits. This finding indicates that these cracks existed at the time the spacer was last inspected since nickel deposits are introduced during NiCd replating of the spacer. The AeroThrust Corporation (A.C.E.S. in 1981) work order for the spacer showed that the NiCd plating had been stripped from the part during its rework and that the part was free of cracks. The Safety Board believes that cracks were present at the time of the inspection and should have been detectable using FMPI methods. However, the Board does not believe that these cracks precipitated the rupture of the spacer.

Testimony by Pratt & Whitney representatives revealed that the most common failure mode of high pressure compressor spacers involved cracks which were initiated by the knife edge rubbing against the stationary seal land. Fatigue cracks would propagate through the knife edge and pedestal (which supported the knife edge) and then into the spacer barrel until the spacer ruptured. Examination of the failed 9-10 spacer disclosed evidence that cracks had probably initiated in the knife edge and propagated to failure after entering the spacer barrel. The exact origination point could not be identified because the knife edge and part of the pedestal were abraded away, probably during the rupture and ejection of the spacer from the engine. Crack growth data showed that the number of cycles required for a 10-mil crack to propagate to failure (almost 21,000 cycles) were much more than the number of cycles recorded on the engine subsequent to the overhaul (2,584 cycles). Therefore, the originating crack which existed at the time of the spacer overhaul should have been much longer than a 10-mil length and should have been detectable during the 1981 spacer overhaul.

The Safety Board believes that a thorough inspection of the spacer at the time of the 1981 spacer overhaul should have revealed the crack(s) and prevented the subsequent failure of the spacer. Since AeroThrust did not maintain records showing how the Magnaflux inspector was trained or recurrently qualified and it did not have records of the inspector's required annual vision checks, the Safety Board was unable to resolve whether the inspector's training, proficiency, or vision was responsible for his failure to discover cracks during the 1981 inspection of the 9-10 spacer. The Safety Board believes that engine overhaul facilities should document accurately the training of its key inspector personnel and that FAA PMIs should not allow deficiencies in inspector qualification and training records to exist, as they did at A.C.E.S. and AeroThrust Corporation.

The Safety Board found that the PMI assigned to AeroThrust at the time of the accident had been responsive to deficiencies noted at AeroThrust and that FAA surveillance had increased significantly since his assignment to that certificate in 1985. The Board is concerned, however, that earlier documented FAA surveillance did not identify calibration equipment deficiencies and training record deficiencies which apparently had existed for years at AeroThrust. The Board believes that jet engine repair facilities require more surveillance and guidance from the FAA than was provided to AeroThrust (A.C.E.S.) in 1980-1981 and, therefore, that FAA surveillance of AeroThrust was deficient during that period. The Board concludes that increased FAA surveillance should yield stricter adherence to establish procedures, improved training and recordkeeping, and would, in the future, produce a more capable repair station inspector workforce.

2.7 Removable Sleeve Spacer Fractures

As a result of the Midwest Express accident and a series of incidents which involved the failure of removable sleeve spacers in high pressure compressors of JT8D engines, on November 8, 1985, the Safety Board recommended that the FAA:

A-85-120

> Issue an Airworthiness Directive (AD) to require the installation of the one-piece, integral sleeve spacer at all six locations in the high-pressure compressor rotor of Pratt & Whitney JT8D-series engines not so equipped. The installation should be made as soon as practical but not later than the next opportunity wherein the engine is available in the maintenance facility where a partial or complete disassembly of the compressor can be accomplished.

On January 2, 1986, the FAA published a Notice of Proposed Rulemaking (NPRM) in which it proposed to issue an AD that would require:

(1) A one-time, on-wing, eddy current inspection of stages 7-8, 8-9, and 9-10 HP compressor removable sleeve spacers in accordance with Pratt & Whitney Alert Service Bulletin (ASB) No. 5649;

(2) Replacement of stages 7-8 and 9-10 stage removable sleeve spacers at next HP compressor rotor disassembly within the next 2 years or 4,000 cycles, whichever is later; and

(3) Replacement of the 8-9, 10-11, 11-12, and 12-13 stage removable sleeve spacers with integral sleeve spacers, whenever the HP compressor is disassembled.

On February 18, 1986, the Safety Board commented on the NPRM, recommending that the 7-8 and 9-10 stage removable sleeve spacers be replaced as soon as practical--that is, the next time the engine was in a maintenance facility in which the compressor could be partially or completely disassembled, but not later than 4,000 cycles time-in-service from the effective date of the AD.

The Safety Board's comments were based on its understanding that the on-wing eddy current inspection could detect a crack in the pedestal of the spacer just below the knife edge seal and that an existing crack, undetected by the inspection, would therefore take at least 8,000 cycles to propagate through the pedestal and into and across the barrel of the spacer. However, the Safety Board was subsequently informed by Pratt & Whitney that the on-wing inspection would not necessarily detect a crack until it had propagated almost into the spacer barrel, at which time fracture of the spacer could occur in about 1,000 cycles.

The Safety Board was concerned that the 4,000 cycles, or 2 years, whichever was longer, provided by the proposed AD would not adequately protect against additional spacer ruptures and possible damage to vital components of airplanes. As a result of these concerns and other considerations, the Safety Board concluded that the on-wing eddy current inspection required by the proposed AD and set forth in Pratt & Whitney Alert Service Bulletin (ASB) No. 5649 must be repeated at 1,000-cycle intervals until stage 7-8, 8-9, and 9-10 removable sleeve spacers within the engine have been replaced with one-piece integral sleeve spacers. Consequently, on April 7, 1986, the Safety Board recommended that the FAA:

A-86-28

Issue a Telegraphic Airworthiness Directive and amend the airworthiness directive proposed in the Notice of Proposed Rulemaking published at 51 FR 37, Docket No. 85-ANA-46, to require that the one-time, on-wing eddy current inspection specified in the proposed airworthiness directive be repeated at 1,000-cycle intervals until stage 7-8, 8-9, and 9-10 removable sleeve spacers between the high-pressure compressor are replaced with integral sleeve spacer.

As a result of its issuance of Safety Recommendation A-86-28 which updated the Safety Board's concerns about JT8D removable sleeve compressor spacers, Safety Recommendation A-86-120 was classified as "Closed--Superseded."

On May 13, 1986, the FAA issued Airworthiness Directive (AD) 86-08-04 which requires eddy current inspection and subsequent replacement of high pressure compressor (HPC) removable sleeve spacers on certain JT8D engines. Although the AD was responsive to the intent of Safety Recommendation A-85-120, it was not fully responsive to the concerns expressed to the FAA in Safety Recommendation A-86-28. The Safety Board has learned that the FAA declined to modify AD-86-08-04 as recommended by the Board. The Safety Board takes exception to the FAA's position that repetitive eddy current inspections are not necessary. In the Board's opinion, eddy current inspections should be repeated at 1,000-cycle intervals until the subject removable sleeve compressor spacers are removed from service. The Safety Board has classified Safety Recommendation A-86-28 as "Closed—Unacceptable Action," but will continue to voice its concerns should additional failures of removable sleeve spacers continue. The Safety Board remains convinced that prompt replacement of removable sleeve compressor spacers in JT8D engines, with integral sleeve spacers, is the best solution to the spacer rupture problem.

2.8 Flight Data Recorder

The Safety Board has repeatedly expressed views that the flight data recorders of the U.S. airline fleet are not totally adequate for accident investigation purposes. N100ME was equipped only with a five parameter metal foil analog FDR, as are most other turbojet transports for which type certificates were issued before September 30, 1969, even though they may have been manufactured and introduced into the fleet more recently. Consequently, the Safety Board was deprived of data regarding the airplane's engine performance, flight control positions, inertial attitudes, and accelerations, all of which would have provided information essential to support the theoretical analysis of the factors leading to the airplane's departure into an uncontrollable descent. The Safety Board was able to determine engine thrust level, a key element in the accident analysis, from the engine sounds recorded on the airplane's CVR. However, this was fortuitous in this investigation since engine sounds are seldom discernible on the CVR in those airplanes with aft fuselage mounted engines. Engine thrust data, as well as the flight control and inertial data required for a more comprehensive analysis of this accident are required to be recorded on the digital FDRs installed on airplanes certificated after September 30, 1969.

In recognition of the shortcomings of the FDRs required on the earlier type-certificated airplanes, the Safety Board on July 13, 1982, issued Safety Recommendations A-82-64 through -66 to the FAA:

<u>A-82-64</u>

Amend 14 CFR 121.343 so that, after a specified date, all turbojet aircraft manufactured before that date and type-certificated before September 30, 1969, be required to have installed a suitable digital recorder system capable of recording data from which the minimum following information may be determined as a function of time within the ranges, accuracies, and recording intervals specified in Table I--altitude, airspeed, heading, radio transmitter keying, pitch attitude, roll attitude, vertical acceleration, longitudinal acceleration, stabilizer trim position, engine thrust, and pitch control position.

<u>A-82-65</u>

At an early date and pending the effective date of the recommended amendment of 14 CFR 121.343 to require installation of digital flight data recorder systems capable of recording more extensive parameters, require that operations of all aircraft equipped with foil flight data recorders be required to replace the foil recorder with a compatible digital recorder.

A-82-66

Amend 14 CFR 121.343 so that, after a specified date, all aircraft manufactured after that date, regardless of the date of original type certificate, be equipped with one or more approved flight recorders that record data from which information listed in Table I can be determined as a function of time. For newly type-certificated aircraft, any dedicated parameter which may be necessary because of unique features of the specific aircraft configuration and the type design should also be required.

On January 8, 1985, the FAA issued a Notice of Proposed Rulemaking, the substance of which proposes retrofit of digital type recorders with added parameters on all transport airplanes not so equipped. Although the Safety Board believes that requirements even more stringent than those proposed are needed, the Board supported the proposed rulemaking and acknowledged that it would be a significant step toward improving flight recorder standards. The Board is very concerned that 2 years have passed since the initiation of the rulemaking action and a final rule is yet to be adopted.

The Safety Board further notes that the aviation regulatory authorities of other countries progressive in the aviation field have adopted FDR requirements more stringent than those required or even proposed by the FAA. In fact, the International Civil Aviation Organization (ICAO) has adopted standards which are consistent with Safety Board recommendations. The Safety Board will continue to urge the FAA to expedite the rulemaking actions to upgrade flight recorders on the U.S. airline fleet and to ultimately require that new airplanes be equipped with recorders which met ICAO standards.

Pending further FAA action, Safety Recommendations A-82-64 through -66 have been classified as "Open-Acceptable Action."

3. CONCLUSION

3.1 Findings

1. The flightcrew was medically and operationally qualified and well rested before the flight. There was no indication of chronic or life event stress-related factors which would have affected the performance of either pilot.

2. N100ME was certified, equipped, and maintained in accordance with FAA rules. There were no uncorrected discrepancy reports which involved powerplants or control systems.

3. N100ME was dispatched within the applicable weight and center of gravity limitations.

4. The aircraft performance was normal during the takeoff and initial climb phases of flight until the right engine failed at 450 feet a.g.l. at a speed well in excess of the takeoff safety speed (V2).

5. The right engine failed abruptly and completely due to the uncontained failure of the 9th to 10th stage high pressure compressor spacer.

6. Uncontained pieces of the ruptured spacer did not cause any significant damage to the airplane fuselage, control systems, or the left engine.

7. The right engine failure was precipitated by a fatigue crack in a knife edge of the 9th to 10th stage spacer. The crack had propagated to a length which should have allowed detection on the occasion of the last high pressure compressor overhaul and spacer rework in 1981.

8. None of the airplane flight control systems were disabled.

9. The cause of the left engine power loss, which occurred beginning about 1.5 seconds after the right engine failed, was not determined.

10. The left engine experienced a compressor stall in the last seconds of the flight after control had been lost and the airplane was descending toward the ground in an unusual attitude.

11. The loss of left engine power was not significant with respect to the loss of control of the airplane.

12. The captain initially responded correctly with deflection of the rudder pedal to the left to compensate for the loss of right engine thrust and by lowering the nose of the aircraft; however, he appeared to be unaware of the exact nature of the emergency.

13. The crew response to the right engine failure was not coordinated.

14. Neither pilot verbally identified the emergency condition or made the emergency callouts required by FAA-approved Midwest Express procedures.

15. The rudder was incorrectly deflected to the right 4 to 5 seconds after the right engine failure.

16. An accelerated stall and loss of control occurred 10 seconds after the failure of the right engine.

17. Forward visual cues (outside the cockpit) were not available to the crew at the time that the right engine failed. Peripheral visual cues were available.

18. The visual flight simulator, which was used by the crewmembers in training, did not provide onset yaw and longitudinal acceleration cues, peripheral visual cues, or aural cues which were available to the crew in the airplane.

19. The captain and first officer misinterpreted the inside visual cues which were presented in the airplane.

20. The differences in visual motion and aural cues presented in the visual flight simulator and in the airplane may have limited the ability of the flightcrew to recognize and react appropriately to the emergency.

21. Failure to recognize the nature of the emergency and improper operation of flight controls precipitated the loss of control.

22. The DC-9-14 does not require unusual pilot skill or strength to maintain continued flight following an engine failure on takeoff.

23. Both crewmembers were relatively inexperienced in DC-9 flight operations.

24. The FAA Principal Operations Inspector who was responsible for oversight of Midwest Express was inexperienced in FAR 121 turbojet air carrier operations.

25. A "silent cockpit" philosophy was suggested by Midwest Express in response to certain emergency situations, although the concept was not approved by the FAA and was in conflict with approved emergency procedures.

26. FAA surveillance of Air Carrier Engine Service (AeroThrust) was deficient in the 2-year period which preceded the overhaul of the 9-10 spacer.

27. The accident was nonsurvivable because the impact forces exceeded the limitations of human tolerance.

*3.2 Probable Cause

The National Transportation Safety Board determines that the probable cause of the accident was the flightcrew's improper use of flight controls in response to the catastrophic failure of the right engine during a critical phase of flight, which led to an accelerated stall and loss of control of the airplane. Contributing to the loss of control was a lack of crew coordination in response to the emergency. The right engine failed from the rupture of the 9th to 10th stage removable sleeve spacer in the high pressure compressor because of the spacer's vulnerability to cracks.

4. RECOMMENDATIONS

On November 8, 1985, the Safety Board recommended that the Federal Aviation Administration:

A-85-120

Issue an Airworthiness Directive (AD) to require the installation of the one-piece, integral sleeve spacer at all six locations in the high-pressure

*ICAO Note.— The term *probable cause* is not envisaged in Annex 13, nor in the *Manual of Aircraft Accident Investigation* (Doc 6920).

compressor rotor of Pratt & Whitney JT8D-series engines not so equipped. The installation should be made as soon as practical but no later than the next opportunity wherein the engine is available in the maintenance facility where a partial or complete disassembly of the compressor can be accomplished.

A-85-121

Notify appropriate foreign civil aviation authorities and foreign operators of airplanes equipped with Pratt & Whitney JT8D-series engines of the failures associated with the removable sleeve spacers installed in the high-pressure compressor rotor and of the actions which should be taken to minimize or eliminate the failures.

On April 7, 1986, the Safety Board recommended that the Federal Aviation Administration:

A-86-28

Issue a Telegraphic Airworthiness Directive and amend the airworthiness directive proposed in the Notice of Proposed Rulemaking published at 51 FR 37, Docket No. 85-ANA-46, to require that the one-time, on-wing eddy current inspection specified in the proposed airworthiness directive be repeated at 1,000-cycle intervals until stage 7-8, 8-9, and 9-10 removable sleeve spacers between the high-pressure compressor are replaced with integral sleeve spacers.

As a result of its investigation, the Safety Board recommended that the Federal Aviation Administration:

Issue an air carrier operations bulletin directing Principal Operations Inspectors to review their respective air carrier's flightcrew training programs to ensure the existence of new coordination procedures that, notwithstanding a policy endorsing nonessential conversation during an emergency condition, require any crewmember who observes a potential or actual emergency situation to verbally call it to the captain's attention. (Class II, Priority Action) (A-87-8)

Issue an air carrier operations bulletin directing Principal Operations Inspectors to review their respective air carrier's simulator training programs to verify that engine failures in the posttakeoff climb are frequently given with particular emphasis on the use of engine and flight instruments as the primary source of information for airplane control and on the need for deliberate actions based upon flight and engine instrument analysis rather than hasty action based upon kinesthetic cues. (Class II, Priority Action) (A-87-9)

Require Principal Operations Inspectors of 14 CFR 121 certificate holders to have training and experience commensurate with the air carrier involved, including a comparable type rating (e.g., turbojet powered transport category) in the category and class of aircraft to be used by the certificate holder. (Class II, Priority Action) (A-87-10)

DISSENTING STATEMENT

The Chairman filed the following dissenting statement regarding probable cause and contributing factors:

The probable cause of the accident was the catastrophic failure of a high pressure compressor spacer in the right engine during a critical phase of flight, together with the flightcrew's improper use of the flight controls that resulted in an accelerated stall and loss of control of the airplane.

Contributing to the cause of the accident was a training program which inadequately prepared the flightcrew to diagnose and respond to an engine-out situation in the climb-out phase of flight, a lack of crew coordination in response to the emergency, and the inadequate inspection of the compressor spacer at the engine repair facility.

ICAO Note.— Section 1.17, Figures 1,3,4,6 and 7, and Appendices A to I were not reproduced.

ICAO Ref.: 215/85

No. 8

IAI 1124 Westwind, VH-IWJ, accident near Sydney, Australia, on 10 October 1985. Report No. 852-1056 released by the Bureau of Air Safety Investigation, Australia

SYNOPSIS

At approximately 0059 hours Eastern Standard Time (EST) on 10 October 1985 Israel Aircraft Industries (IAI) 1124 Westwind aircraft, registered VH-IWJ, crashed into the sea off the South Head of Botany Bay, New South Wales (NSW). The wreckage came to rest in 92 metres of water.

VH-IWJ was engaged in operating a cargo flight with a crew of two pilots and carrying no passengers. Both members of the flight crew received fatal injuries and the aircraft was destroyed.

1. FACTUAL INFORMATION

1.1 HISTORY OF THE FLIGHT

IAI 1124 Westwind aircraft, registered VH-IWJ, was operating under a current Certificate of Registration, the holder of which was Pel-Air Aviation Pty Ltd (Pel-Air). The aircraft was operated by Pel-Air and, at the time of the accident, it was engaged on a regularly scheduled cargo service. This service was operated under the terms of a current Charter and Aerial Work Licence, and was flown on behalf of Ansett Air Freight, a subsidiary of Ansett Transport Industries Pty Ltd. The particular flight, designated Flight 474, was operated on 4 nights each week from Sydney to Brisbane and Cairns, Queensland.

The aircraft had departed Cairns earlier in the evening and had flown via Brisbane to Sydney, arriving at 2336 hours. The arriving crew reported that the aircraft was performing normally. A total of 1350 litres of fuel was added to the aircraft tanks and loading of general cargo was carried out by Ansett Air Freight personnel.

The flight plan submitted to Air Traffic Control (ATC) indicated that the flight would follow the normal Instrument Flight Rules (IFR) procedures.

Note : All times shown are Australian Eastern Standard Time (Greenwich Mean Time plus 10 hours), and are based on the 24-hour clock.

The estimated time interval to Brisbane was 70 minutes at planned Flight Level 370 (approximate altitude of 37000 feet). The aircraft carried sufficient fuel for 164 minutes of flight, and refuelling was planned to take place at Brisbane prior to departure for Cairns.

Pel-Air intended to use the flight to assess the performance of the rostered co-pilot, who was being considered for upgrading to command status. He was to occupy the left hand control seat, while the right hand seat occupant was the Chief Pilot of the company.

At 0033 hours the crew established radio contact on the Sydney ATC Clearance Delivery frequency, and were given a "16 West Maitland One" Standard Instrument Departure (SID). The flight pattern associated with this clearance requires the aircraft to maintain heading after take-off on Runway 16 until reaching a height of 500 feet, when a left turn is made to intercept the 126 radial of the Sydney VOR (Very High Frequency Omni-directional Range). At a position of 6 nautical miles by Distance Measuring Equipment (DME) from the aerodrome, a left turn onto 357 degrees is made in order to continue tracking with reference to the West Maitland VOR. A copy of the applicable SID chart is shown at Appendix A.

Shortly before 0049 hours the crew contacted Sydney Control Tower, and the aircraft was directed to taxi for a departure from Runway 16. At the time the wind was light and variable. After receiving the appropriate clearance, an evidently normal take-off was made, and at 0056 hours contact was established with Sydney Departures Control. The pilot in command advised that the aircraft was on climb to Flight Level 370 , and requested the direct track to Brisbane. This was a standard request, to allow the aircraft to proceed directly to the destination rather than follow the various radio navigation aids along the route. Such a request was normally granted by ATC if the general traffic situation permitted use of the direct track, and provided the aircraft was equipped with a suitable navigation system. VH-IWJ was fitted with a VLF/Omega navigation system which was capable of direct tracking. After ascertaining this, the Departures controller advised the aircraft that the direct track to Brisbane would probably be available. The acknowledgment of this comment was the last recorded transmission from the aircraft.

Shortly before 0059 hours the Departures controller broadcast the clearance for the aircraft to track direct to Brisbane at the planned cruising level. No response was received from the aircraft, although the controller noted that radar returns were still visible on his screen. Shortly afterwards, these returns faded, and the Distress Phase of Search and Rescue procedures was instituted at 0100 hours.

At about this time, a number of persons observed what appeared to be the lights of an aircraft descending rapidly towards the sea. The lights maintained their position relative to each other, indicating that the aircraft was not rotating as it descended.

The aircraft had faded from the radar screen at a point about 11 kilometres south-east of Sydney Airport. A search of the area was commenced using helicopters and boats. Wreckage identified as being from the aircraft was sighted by a helicopter at 0245 hours. Recovery of pieces of the aircraft structure, freight and human remains was effected by Police and Department of Aviation launches. The degree of destruction indicated that the aircraft had struck the water while travelling at high speed.

The bulk of the wreckage was presumed to be lying in about 85 metres of water about 5 kilometres out to sea from Botany Bay. An intensive search was carried out by vessels from the Royal Australian Navy, later assisted by a vessel from the NSW Department of Fisheries and Agriculture. Use was made of various underwater detection devices. Search efforts were hampered by persistent unfavourable sea conditions and no trace was found of the wreckage. Operations were finally suspended towards the end of November 1985. An internationally recognised underwater location and salvage expert was then employed, and the wreckage was ultimately located and identified in 92 metres of water on 20 January 1986. Recovery of the Flight Data and Cockpit Voice Recorders, the major portions of both engines, and sundry other pieces of the aircraft structure, was effected the following month.

1.2 INJURIES TO PERSONS

Injuries	Crew	Passengers	Others
Fatal	2	-	-
Serious	-	-	-
Minor/None	-	-	
Total	2		

1.3 DAMAGE TO AIRCRAFT

The aircraft was destroyed.

1.4 OTHER DAMAGE

No other property was damaged during the accident sequence.

1.5 PERSONNEL INFORMATION

The pilot in command of the aircraft, , age 40 years, was the Chief Pilot and the Chief Check and Training Pilot for Pel-Air. He was the holder of a Senior Commercial Pilot Licence which was current to 28 February 1986. This licence was appropriately endorsed to permit him to operate as pilot in command of the IAI Westwind type. He was also the holder of a First Class Instrument Rating, endorsed for appropriate navigation aids, which permitted him to operate aircraft under IFR procedures. Mr 's total flying experience at the time of the accident was 9881 hours, of which 3101 hours had been gained in the Westwind type. 2973 hours of these had been accumulated while acting as pilot in command of the type. His most recent proficiency check had been successfully completed on 21 May 1985 and his most recent pilot's medical examination had been completed on 28 August 1985. In the 90 days preceding the accident he had flown a total of 195 hours, all on the Westwind type. In the 7 days preceding the accident he had flown 16 hours 15 minutes on 4 separate flights. 157 of the hours in the 90 day period had been flown at night, and the accident flight was to be his third consecutive night of duty. He had been off duty since 0930 hours on 9 October and did not return to duty until approximately 0020 hours on 10 October.

The co-pilot of the aircraft was , age 37 years. He was the holder of a current Senior Commercial Pilot Licence, which was valid to 30 November 1985. This licence was appropriately endorsed to permit him to act as a co-pilot on the Westwind type. He also held a Second Class Instrument Rating, endorsed for appropriate navigation aids, which permitted him to operate under IFR procedures. At the time of the accident he had accumulated 8091 hours flying experience, of which 500 had been gained as a co-pilot on Westwind aircraft. His most recent proficiency check had been completed on 3 October 1985, and his most recent aircrew medical examination had been conducted on 29 May 1985. In the 90 days preceding the accident he had flown 190 hours, all on Westwind aircraft; 154 of these were flown at night. In the preceding 7 days he had flown 19 hours 50 minutes during 3 flights. He had been off duty since completing a return flight from Darwin in the early hours of 9 October 1985.

A vacancy existed within Pel-Air for a pilot in command for Westwind aircraft. Mr had indicated his desire for this position, and had undergone an appraisal flight on 2 and 3 October 1985. The flight had been under the command of Mr , who subsequently advised the company management that Mr had not performed to a satisfactory standard. Mr had been counselled on his performance, and had then spent a considerable amount of time studying the appropriate books and manuals, in preparation for a further appraisal on the flight on which the accident occurred.

1.6 AIRCRAFT INFORMATION

1.6.1 History

VH-IWJ was an IAI 1124 Westwind aircraft, the construction of which had been completed early in 1982 by Israel Aircraft Industries. It had been allotted the manufacturer's serial number 371. The aircraft was purchased by the original owner, Resources Jet Charter, and was flown to Australia in April 1982. It had then been operated by a number of charter companies until Peldale Pty Ltd acquired it in November 1984. In February 1985 Peldale Pty Ltd became Pel-Air Aviation Pty Ltd. This company continued to hold the aircraft Certificate of Registration, and operated and maintained the aircraft. At the time of the accident it had flown a total of 3105 hours since new.

1.6.2 Loading

The maximum permissible gross weight for take-off for the aircraft, having regard to structural limitations, was 10660 kilograms (kg). Runway 16 at Sydney Airport was sufficiently long for the aircraft to be able to operate at this weight. The actual weight of the aircraft at take-off was calculated to have been 8234 kg, including 1047 kg of cargo. Much of the cargo was of a bulky nature, and the freight carrying capacity of the aircraft was limited by volumetric, rather than weight, considerations. The centre of gravity of the aircraft was within the specified limits and there was adequate fuel on board for the proposed flight.

1.6.3 Fuel Considerations

The total fuel capacity of the aircraft was 3959 kg. At the time the aircraft landed at Sydney Airport there was approximately 509 kg of fuel remaining in the tanks. Under instructions from Mr   , 1100 litres (870 kg) of aviation turbine (Avtur) fuel was added by the BP company refueller. The crew then became aware from the Briefing Office that the weather at Brisbane was expected to deteriorate shortly after the planned arrival time. Although there was no requirement for extra fuel to be carried, the pilot in command elected to uplift a further 250 litres (198) kg, making the total fuel load 1577 kg.

The tanker used to dispense the fuel into VH-IWJ had been checked for water contamination earlier in the day. None had been found, and four other aircraft had been refuelled prior to the initial 1100 litres supplied to VH-IWJ. The tanker had subsequently been replenished from depot stocks and again found free of water contamination. Another aircraft had then been refuelled from the tanker prior to the final 250 litres added to VH-IWJ.

Immediately following notification of the accident, the fuel batch was quarantined. Preliminary, and subsequently extensive, quality control checks confirmed that the fuel as supplied was uncontaminated and met the appropriate product specifications.

1.6.4 Maintenance and Serviceability.

There was a current Certificate of Airworthiness for the aircraft, and required maintenance had been carried out in accordance with a system which had been approved by the then Department of Transport in 1979. The system called up various items for maintenance and servicing each 150 hours of flight time, plus additional checks which were required every 75 hours.

A number of documents were used to record and control maintenance activity. These were as follows:

(a) Scheduled Maintenance and Rectification Sheets (SMRS). These forms are used to call up the maintenance required at a check inspection and to record and certify the action taken. They are also used to record defects found during the maintenance, and corrective action taken.

(b) Component History (CH), and Overhaul and Special Inspection Period (OSIP) cards. The CH cards record the movement and time in service of interchangeable components, while the OSIP cards specify the maintenance required on interchangeable components and record maintenance carried out on these items.

(c) Aircraft Maintenance Log. This is a booklet containing numbered coupons, which are used to record defects occurring between scheduled inspections and any rectification action taken.

(d) Deferred Log. This is a booklet, carried in the aircraft, which contains details of any entries in the Aircraft Maintenance Log on which action has been deferred.

(e) Permissible Unserviceability Schedule. This document forms part of the company operations manual for the aircraft type. It contains a listing of the various components which are not considered to be critical for normal flight operations, and may be temporarily unserviceable. The schedule is approved by the Department of Aviation, and may be varied on application by the operator.

The aircraft had flown a total of 59.5 hours in service since the last scheduled maintenance inspection, which had been completed on 26 September 1985. Two reported defects had not been rectified during this inspection, and entries in the Aircraft Maintenance Log indicated that the details had been transferred to a SMRS. One concerned spurious warnings being given by the altitude alerting system, and a note on the SMRS indicated that spare parts were awaited for this equipment. This particular defect was not considered to be relevant to the circumstances of the accident. The other defect concerned the rate of turn indicator fitted to the Flight Attitude Director Indicator on the left instrument panel. The rate of turn indicator was known to be operating in the reverse sense i.e., with the aircraft turning to the left the indicator showed that a right turn was taking place, and vice versa. This defect is discussed at paragraph 1.6.4.2.

1.6.4.1 Attitude Instruments Required for Flight

The cockpit configuration of VH-IWJ provided 3 separate flight attitude indicators. These were:

a) the pilot's Flight Attitude Director Indicator, which incorporates a flight director facility and provides flight attitude, as well as other information to the pilot. The attitude signals are provided by the flight guidance computer which is powered by the No.1 AC Bus at 115 volts alternating current (115Vac). A full-scale diagrammatic illustration of this instrument is shown at Figure 1.

b) the co-pilot's flight attitude indicator which is a self contained instrument and is powered by the No.2 Instrument Bus at 26Vac.

c) the emergency attitude indicator which is also self contained and is powered from the No.2 Communications and Accessories Bus at 28 volts direct current (28Vdc). This instrument is located on the left instrument panel. It is also fitted with an emergency battery which will power it for 30 minutes after any interruption to its principal power supply.

To avoid confusion, these three attitude instruments will be referred t' throughout this report as Flight Attitude Indicators (FAI).

1.6.4.2 Instrument Unserviceability.

Under the terms of the relevant Air Navigation Orders, as the aircraft was fitted with three independently powered attitude indicators, there was no requirement for it to be equipped with a rate of turn indicator. However, as the indicator was fitted, and was not included in the aircraft Permissible Unserviceability Schedule, it was required to be operating correctly prior to take-off.

The rate of turn indicator, which formed part of the pilot's FAI, had first been reported as operating in the reverse sense on 23 October 1984. This report had been entered in the aircraft maintenance log by Mr Haskett. At that time the aircraft was being operated by Wings Australia Pty Ltd and had accumulated 1487 hours time in service since new. Maintenance personnel had been unable to isolate and rectify the fault, which was reported in the log on three further occasions.

The rate of turn system has three main components. These are:

(a) a sensor, which is a gyro that senses the direction and rate of turn of the aircraft and converts this information into electric current for transmission to the rate of turn indicator. This sensor is mounted beneath the cabin floor.

(b) a rate of turn indicator, which is a simple ammeter calibrated to indicate the degree and direction of turn of the aircraft. It achieves this by responding to the electric current originating from the sensor referred to above. It is mounted on the lower casing of the pilot's FAI.

(c) the interconnecting wiring between the sensor and the indicator.

After the first report of the unserviceability of the system the relevant engineering staff carried out a number of checks and component changes to rectify the fault. Three different indicators and two different sensors were fitted to the aircraft at different times during the period of the reports. All of these units when fitted to other aircraft operated correctly, but when fitted to VH-IWJ the rate of turn indicator operated in the reverse sense. The engineering staff reported that they had carried out continuity checks on the wiring between the two components and those checks had confirmed that the aircraft was wired in accordance with the aircraft wiring diagrams. Nevertheless, it was considered likely that a fault had existed in the aircraft wiring, but the investigation was unable to determine the precise circumstances under which such a fault might have occurred.

1.7 METEOROLOGICAL INFORMATION

At 0100 hours a meteorological observation was taken at Sydney Airport. This recorded the surface wind as 158 degrees magnetic at 2 knots, visibility 30 km, cloud one octa (eighth) of strato-cumulus at 5000 feet, temperature 17 degrees Celsius (C) and QNH (altimeter sub-scale setting) 1020 millibars (mb). The Pilot Balloon flights from Sydney Airport conducted 4 hours prior to, and 2 hours after the accident recorded nothing that was considered of causal significance. On that morning, the moon did not rise until 0315 hours.

Recorded weather information was available via the Automatic Terminal Information Service (ATIS). The information current as the aircraft was prepared for departure was coded Alpha, and advised that the wind was light and variable, with a downwind component of 2 knots on runway 34. The QNH was 1019 mb, temperature was 16 degrees C, and there was one octa of cloud at 2500 feet.

1.8 AIDS TO NAVIGATION

All of the departure aerodrome and relevant en-route navigation aids were serviceable at the time of the accident.

1.9 COMMUNICATIONS

All the required transmissions to and from the aircraft were made on the correct frequencies. Neither the flight crew nor ATC reported any difficulty with communications until the aircraft failed to reply to the ATC instruction to track direct to Brisbane.

1.10 AERODROME INFORMATION

Sydney (Kingsford-Smith) Airport is located on the Northern shore of Botany Bay and has two intersecting runways. Runway 16 was in use for departing aircraft at the time. This is the preferred runway for night operations, in order to minimise the effects of aircraft noise on suburbs adjacent to the airport. The runway has dimensions of 3962 x 45 metres and extends into the Bay for some 2000 metres. It is aligned in a direction of 156 degrees magnetic.

The Sydney Control Tower is located to the south-west of the runway intersection and affords an unobstructed view of the the runways and taxiways to the tower controllers. The Surface Movement Controller and Aerodrome Controller are located in the Tower. The Departures Controller who monitors the path of aircraft, primarily by radar, is located in the Area Approach Control Centre (AACC) at the base of the Tower. The returns received by the radar antennae heads are processed and transmitted to the screens in the AACC. These radar antennae, for the Terminal Area and Route Surveillance Radars, are located East of the runway intersection. The Senior Area Approach Controller confirmed the serviceability of the radar equipment with the technicians on duty at the time of the accident.

1.11 FLIGHT RECORDERS

1.11.1 Cockpit Voice Recorder

The aircraft was equipped with a Fairchild A100 Cockpit Voice Recorder (CVR) of conventional configuration applicable when the aircraft was first registered in Australia. The CVR system is an audio recording system which uses magnetic tape to retain the last thirty minutes of information. The tape is a continuous loop whereby previous information is progressively erased as new recording takes place. Recording is commenced when power is selected on to the No.2 AC Bus and the Avionics Master Switch is on. The CVR system fitted to VH-IWJ allowed for the recording of radio and cockpit intercom transmissions. A separate track on the tape was used to record the sounds detected by a remote cockpit area microphone (CAM). The CAM was situated on the CVR control panel, which was in the centre console between the two crew seats. This CAM track was the source of all recorded conversation between the pilots and the various background noises heard during the flight.

The CVR was recovered relatively intact. Although mounted in the tailcone area it had suffered substantial damage to the front of its case at the time of impact. Water had penetrated the tape mechanism protective case and corrosion products had attacked the tape where it was in contact with the recording heads. The tape itself had been broken by impact forces at the point where it crossed from the inside of the reel to the recording heads. The tape covered 30 minutes of aircraft operation, 12 minutes of which related to the accident flight, beginning at the time of the first engine start. The last half second of the accident flight recording was degraded due to the tape being affected by corrosion products.

All air/ground transmissions were recorded satisfactorily and the CAM provided a good recording of the total audio environment in the cockpit. Crew conversation recorded by the CAM was readily intelligible during the ground operation of the aircraft. However, after take-off power was applied a high level of background noise tended to mask the comments made by the pilots. Considerable effort was required, including spectral analysis, signal enhancement and test recordings made in other Westwinds, in order to complete a transcript of recorded information. Extracts from this transcript are reproduced at Appendix C.

The CVR was not fitted, and was not required to be fitted, with an underwater locator beacon (ULB).

1.11.2 Flight Data Recorder

The aircraft was fitted with a Fairchild 5424-501 Flight Data Recorder (FDR) in accordance with requirements applicable at the time the aircraft was entered on the Australian Register. This FDR is an analogue type that records pressure altitude, indicated airspeed, magnetic heading, vertical acceleration and VHF radio keying, against a time base. This information is recorded by inscription on a stainless steel tape. Power is supplied to the FDR from the No.2 Inverter via the Avionics Master Switch No.2. The operator normally selected the Avionics Master Switches "ON" after starting the first engine. The FDR was installed in the tailcone section of the aircraft, however it also suffered substantial damage at impact.

After recovery of the FDR the tape was withdrawn from the unit and although it had been torn during impact, which precluded an exact mating of the torn ends, the recorded data was extracted. A detailed read-out of all recorded information was conducted for a period of 10 minutes up to, and including the impact sequence. This period covered approximately seven minutes of ground operation and about three minutes from the start of take-off to the end of reliable data.

The pressure altitude trace indicated that after becoming airborne the aircraft climbed initially at 1700 feet/minute (fpm). The rate then increased and stabilised at 3300 fpm which was maintained to the maximum recorded pressure altitude of 4700 feet, which corresponded to a height of approximately 5000 feet above sea level. This was reached just over two minutes after take-off, after which the aircraft entered a rapid descent until impact occurred. The average rate of descent over the last 9 seconds of recorded data was in excess of 20,000 fpm.

The airspeed trace indicates that the aircraft accelerated normally and stabilised at a climb speed of 240 knots. At 2 minutes 8 seconds after take-off the airspeed increased rapidly and there was some indication that it may have been stabilising in the region of 420 knots at the time of impact. The recorder is calibrated to register indicated airspeed up to 450 knots.

Magnetic heading data was consistent with the aircraft taxi path and take-off on runway 16 and the subsequent interception of the 126 radial of the Sydney VOR. A left turn was commenced about two minutes after take-off, which corresponds to the aircraft passing the 6 DME Sydney position. However, after turning about eight degrees to the left, the heading change stopped. After remaining steady for about 4 seconds the aircraft heading commenced to change rapidly to the right. Heading information was lost as the turn continued, with the last reliable recording being obtained 15 seconds before the loss of reliable data from the other parameters.

Estimates of the angles of bank achieved during the turn were computed. During the initial turn to the left the bank angle reached 20 degrees. The aircraft then rolled to a wings level attitude before the angle of bank rapidly increased to the right, reaching in excess of 90 degrees.

The vertical acceleration force was normal until the point at which the aircraft commenced the turn to the right. At this time it commenced to increase progressively, until shortly before impact when the recorded value exceeded the calibrated limit of 6g. The recorded increase had been in the positive sense, i.e. following take-off the aircraft did not encounter a vertical acceleration of less than the normal 1g.

The recorder was subject to annual and 1000 hour calibration checks. As it was last calibrated on 20 February 1985 it was within the annual limit. However, the aircraft had flown a total of 1146 hours since that date. It could not be established from the operator's records for how many of these hours the particular recorder had been fitted to VH-IWJ, therefore its calibration compliance status could not be determined. All recorded information was found to be within required tolerances and the data recovered was considered valid. Graphical presentation of the data is shown at Appendix B.

The FDR was equipped with a ULB, which was mounted on the front of the FDR casing. No signals had been received from this device during the search operation. When the FDR was recovered, it was found that the ULB had been disabled as a result of a localised heavy impact, which distorted the case of the unit and damaged the electronics module.

1.12 WRECKAGE AND IMPACT INFORMATION

The first pieces of wreckage were recovered less than 3 hours after the accident at a position 116 degrees magnetic and 7 nautical miles by DME from the Sydney navigation aids. The largest part of the aircraft to be recovered was the outer two-thirds of the right wing including the tip-tank. From the appearance of the items recovered on that morning it was evident that the aircraft had contacted the surface of the sea at very high speed and had been violently destroyed. On 20 January 1986 the remainder of the wreckage was located on the seabed about 1.5 km from the position where the floating debris had been recovered. Information obtained via a video camera confirmed the degree of destruction suffered by the aircraft at the time of initial impact. Despite the recovery of various components from the seabed, it was not possible to establish the precise attitude of the aircraft at the time it struck the water.

1.12.1 Search and Recovery

The Distress Phase of Search and Rescue (SAR) procedures had been declared at 0100 hours. Within 9 minutes of the disappearance of VH-IWJ, another Pel-Air Westwind, which had been preparing to depart for Melbourne, was despatched to the last observed position of VH-IWJ. This aircraft was in the area a short time later but was unable to detect any trace of the missing aircraft. Meanwhile, the Senior Operations Controller (SOC) at Sydney Airport had arranged for three SAR equipped helicopters to assist in the search for the aircraft. The NSW Water Police supplied two launches and the Department of Aviation crash launch was also requested to assist. An offer of help was also received from the Royal Australian Navy, with advice that a helicopter had been launched from a vessel which was in the vicinity.

The first helicopter was in the designated search area within 43 minutes of the aircraft's disappearance and was joined a short time later by the other elements of the search effort. Debris was first located at 0245 hours and the launches were directed to that location. The flotsam consisted of the outer section of the right wing; items of freight; seat cushions; life jackets; oxygen masks and tank; portions of both elevators and other small pieces of the aircraft structure. A small quantity of human remains was also recovered.

A combination of eyewitness evidence, the recollection of the Departures Controller as to the last observed radar position, and the location of the flotsam, was used to determine the most probable position of the remainder of the wreckage. At the request of the Department of Aviation the Royal Australian Navy provided a minehunter vessel, which was to be used to locate the wreckage. Suitable equipment was carried to permit the reception of signals from the ULB. The vessel arrived on-station at 1526 hours on the day of the accident and immediately commenced a search pattern, utilising the ULB signal receivers in addition to the hull mounted sonar equipment. However, throughout the entire search operation, no signals were received from the ULB.

Searching continued until the afternoon of 12 October when adverse weather and sea conditions halted operations for 3 days. During this period a side-scanning sonar device, which was more suitable for the task, was obtained and fitted to the minehunter.

A number of sonar contacts had been made during the early stages of the operation. Water depth in the area precluded the use of conventional diving techniques to obtain positive identification of the various contacts. Use was therefore made of two remote operated vehicles (ROV). These were capable of diving to the depths required, recording the contacts via television cameras, and capable of carrying out limited recovery operations.

Searching activities continued, however a combination of adverse sea states and equipment unserviceability frustrated the effort. Naval support was ultimately withdrawn, but side-scan mapping was continued, using a research vessel, until 22 November. At this time the operation was suspended because of the lack of success in positively locating the wreckage.

Arrangements were made for an American expert in the field of underwater search and recovery of crashed aircraft to travel to Australia, in order to advise on the usefulness of further searching. As a result of this visit, a Sydney based towing and salvage firm was contracted to continue the operation. Specialist men and equipment were provided from the USA, and the Royal Australian Navy again supplied a minehunter vessel. On 20 January 1986, the wreckage of VH-IWJ was located at a depth of 92 metres in position 118 degrees magnetic and 7.3 nautical miles by DME from the Sydney navigation aids. The wreckage formed an elliptical pattern, some 200 metres long and 50 metres wide, aligned in a direction of 328°M. The location was within the original search area. It was evident that the degree of fragmentation of the aircraft, the limitations of the sonar equipment used, and the lack of local expertise in the interpretation of sonar information had precluded its earlier discovery.

Recovery of the wreckage was co-ordinated by the towing and salvage company, with additional vessels provided by the RAN and the Department of Transport. This particular operation was commenced on 20 February 1986, and both the FDR and the CVR were recovered that afternoon. Major portions of both engines and various pieces of the aircraft structure and components were recovered during the following two days. However, the principal recovery vessel dragged its moorings during a period of adverse weather, and the cost and effort required to re-moor the vessel was considered to be uneconomic. All recovery activity ceased on 23 February 1986.

1.13 MEDICAL AND PATHOLOGICAL INFORMATION

1.13.1 Medical Reports

Records maintained by the Department of Aviation showed that both crew members had completed regular six-monthly medical examinations without problems. The only item of significance in Mr 's records related to a long standing mild electrical conduction defect of the heart, which could cause an irregularity of the heart beat. This conduction defect could possibly have been associated with ischaemic heart disease, which results from a restriction of blood vessels supplying the heart. Such a condition places the person at a slightly greater risk of heart attack than the average. No abnormality or irregularity was noted during Mr 's last medical check, which was completed seven weeks prior to the accident.

Mr had suffered a fractured skull in 1966, but there were no associated problems arising from that particular injury and he had no significant medical history.

1.13.2 Pathology

There were insufficient remains recovered for detailed pathological examination. The autopsy was necessarily limited to the identification of the crew members.

1.14 FIRE

There was no fire associated with the development of the accident.

1.15 SURVIVAL ASPECTS

The accident was not survivable.

1.16 TESTS AND RESEARCH

1.16.1 THE CREW

1.16.1.1 The Pilot in Command

Comprehensive interviews were conducted with all the company Westwind pilots and various management personnel. Mr was evaluated by other company pilots as having average manipulative and instrument flying skills for his level of experience. However, they considered that he excelled as an instructor by virtue of his personality, lecturing technique and thorough knowledge of the aircraft and its systems. He was a loyal and hard working employee who disliked inefficiency and laziness, and expected nothing less than 100% effort from other company personnel.

Several company pilots reported that on check flights, Mr in his role of check and training pilot, would introduce simulated systems failures at any stage of the flight. Which systems were involved and the extent of the failure was mostly graded to take into account the experience of the pilot undergoing check. A point made by almost all of the company pilots was that Mr could be relied upon to introduce a unique or obscure failure that had not been covered previously with the candidate. It was also his habit to require the candidate to handle simultaneous systems failures but this was also graded to the experience of the particular pilot. An example of the types of simultaneous and complex failures given related to the loss of various navigation and attitude instruments, coupled with an engine failure, while the pilot was carrying out an instrument approach at night.

Mr expected the company co-pilots to demonstrate their ability to safely control the aircraft by reference to the emergency FAI, following simulated failure of the FAI on the right instrument panel. Some command pilots were expected to make use of the rate of turn indicator, following simulated failures of both FAIs on the left panel. To prevent the pilot obtaining attitude information from the co-pilot's FAI, this instrument was covered, or the cockpit lighting on that side was extinguished. Some of the company pilots had been expected to cope with this emergency exercise immediately after a take-off at night.

1.16.1.2 The Co-Pilot

Mr had previously been based in Darwin with Pel-Air, where he acted as pilot in command on Shorts 3-30 type aircraft. He had applied to be transferred to Sydney when a vacancy became available. After arriving in Sydney to take up the position offered, he had apparently shown little interest in the company. He seemed to be having difficulty in reverting from a pilot in command to a co-pilot, even though the company pilots considered that the Westwind was a more desirable type to operate. Company policy required a co-pilot to have accumulated a minimum of 500 hours on Westwinds before being eligible for command upgrading. When a vacancy for a pilot in command had become available, Mr had lodged an application for the position. He was to be the first co-pilot to be considered for the particular vacancy, because of his overall seniority in the company.

Mr undertook an appraisal flight with Mr on 2 and 3 October 1985. Mr assessed his performance as unsatisfactory, on the grounds of lack of knowledge of the various emergency procedures and the aircraft systems. Counselling was given on these aspects by Mr . Mr was also reminded that it was company policy to permit a first-officer two attempts to upgrade to captain, and should the second attempt be unsuccessful, the candidate remained as a co-pilot indefinitely. At the same meeting he was also counselled by the General Manager on his overall attitude towards the company.

On 7 and 8 October, Mr had flown with another company check pilot, who subsequently reported that in his opinion Mr had made noticeable improvement. However, he had still displayed some lack of knowledge of various procedures, and the actions required in the event of failures of some of the aircraft systems. During the flight Mr was required to control the aircraft using the emergency FAI for attitude guidance, following the simulated failure of the primary FAI. The check pilot reported that Mr handled the exercise without difficulty, and considered that he would make a suitable command pilot, following a period of supervision.

Mr had recently been informed of the unserviceability of the rate of turn indicator in VH-IWJ by one of the company pilots. The flight on which the accident occurred was only the third occasion he had occupied the left hand side control seat, and was the first occasion he had flown VH-IWJ from that seat. It could not be determined whether Mr had required him to fly using the rate of turn indicator during the appraisal flight on 2 and 3 October. However, there was no doubt that Mr had little or no recent experience in the use of this instrument.

Mr had a disturbed sleep on the night preceding the accident flight. This was evidently unusual for him as he was normally able to relax quickly and he had adjusted well to the varying sleep patterns imposed on pilots who must work at night. He had spent most of the previous day studying for the coming flight and he was aware that this was probably his last chance to convince the Chief Pilot of his suitability for upgrading. As he had not complained of any health problem, it is likely that this caused his unrest.

1.16.2 THE AIRCRAFT

1.16.2.1 Structure

The section of right wing recovered on the morning of the accident was examined and determined to have failed in upward bending overload. The wing mainspar failed just inboard of the rib at Wing Station (WS) 93. This position was about 4.5 metres from the outer edge of the wingtip fuel tank. There was no damage to the wing leading edge. However, the trailing edge and the lower rear section of the tip-tank displayed damage consistent with the wing striking the water trailing edge first. No evidence of any pre-existing damage to the wing could be found.

1.16.2.2 Engines

Examination of engine components confirmed that both engines were operating at the time of impact. The compressor blades of both engines showed gross bending against the direction of rotation. This is consistent with high rotational speed of the blades as they came into contact with the diffuser casing. The combustion casing of the right engine was torsionally buckled in the direction of rotation consistent with gross braking loads as the compressor contacted the casing. The left engine tailpipe was subjected to metallurgical examination to determine its temperature when buckled at impact. This was determined to have been in excess of 500°C and is also consistent with the engine operating at high speed at impact.

1.16.2.3 Control Surfaces

Although sections of both elevators were recovered in the same location as the other flotsam on the morning of the accident, little else of the control surfaces or systems was recovered. Due to the other evidence available, it is considered however that these components were not of causal significance.

1.16.2.4 Stabiliser Trim

The horizontal stabiliser jack was recovered attached to a section of the fuselage rear bulkhead and part of the support structure. The right hand screwjack was broken at about half its length and was missing. The left hand screwjack rod end was torn from the horizontal stabiliser front spar attachment point. The distance between rod ends on the left screwjack was measured to determine the stabiliser position before impact. It was established by reference to the maintenance manual that the stabiliser was in a position of -2.6 degrees, which was appropriate for the gross weight and speed of the aircraft at the time.

1.16.3 OTHER RESEARCH

1.16.3.1 Birdstrike

The services of an ornithologist were enlisted to ascertain the likelihood of the aircraft being disabled as a result of a birdstrike. The information obtained revealed that many species of migratory birds fly at night, up to an altitude of about 20000 feet. Although over forty species of shorebirds migrate between Asia and Australia, mainly in October, there is greater movement across Australia from the northwest rather than down the Eastern seaboard. The largest bird likely to be encountered off the East Coast at night during October is the Black Swan whose maximum weight for an adult is 8.75 kg. These are common in southeastern Australia and travel considerable distances at night up to altitudes of 10000 feet. The conditions prevailing at the time of the accident would not have impeded bird flight in any significant way.

After recovery and transcription of the CVR tape it was evident that the aircraft had not suffered a birdstrike.

1.17 ADDITIONAL INFORMATION

1.17.1. Criminal Allegations.

At the time of the accident a number of allegations had been made in the various news media that Pel-Air was involved in the transportation of drugs. Because of these allegations, investigations were carried out by elements of the NSW Police Department. These investigations were carried out with the co-operation of, but independent from, the Bureau of Air Safety Investigation.

A comprehensive forensic examination carried out by the Police found no evidence to support any suggestion that any criminal attempt was made to destroy the aircraft or its crew.

1.17.2 Recorded Radar Information.

When VH-IWJ became airborne from Runway 16, the Departures controller was able to monitor its progress on radar by reference to the primary return from the skin of the aircraft, and a secondary return generated by a transponder in the aircraft. A primary return is generated each time the radar antenna at the Airport receives a skin paint from an aircraft, and the array completes one rotation in approximately 6 seconds. The antenna which receives secondary returns is mounted on the Route Surveillance Radar installation, which takes about 12 seconds to complete each rotation. Information relating to the position and height of the aircraft is updated at this rate.

Considerable difficulty was experienced in determining the exact position at which the returns from the aircraft faded from the radar screen. The last recorded secondary return was received before the aircraft commenced its left turn at about the 6 DME position. However, the controller had observed primary paints from the aircraft as it made the turn. The loss of secondary radar information during a turn is a known phenomenon, occurring as the transponder antenna is shielded by the aircraft structure. At the present time at the major airports in Australia, only the secondary radar information is recorded. As a result, the point at which the controller assessed the aircraft returns had faded depended on his recollections, and could not be positively verified. The likely area in which the aircraft struck the water was therefore unable to be defined as accurately as desired. This in turn led to a dilution of the search effort, with the available resources requiring to be spread over a larger area.

1.18 NEW INVESTIGATION TECHNIQUES

1.18.1 Use of Hypnosis.

One of the principal eye witnesses was a gaol warder. His initial statement on his recollection of the manoeuvres of the aircraft was clear and apparently accurate, however he was unable to recall the whole of the flight path. He agreed to be placed under hypnosis to ascertain whether his memory of the event could be improved.

The exercise was carried out by a NSW Police Department Scientific Squad officer specially trained and approved to place subjects under hypnosis. The interview was conducted by this officer in the presence of investigators. The witness took some time to relax sufficiently to allow himself to become hypnotised, however he then showed graphic recall of the accident. His initial statement had referred only to the observed descent of the aircraft, but he was now able to remember events leading to that descent. He described that he saw the aircraft commence a turn to the left, then roll to the right past the vertical position before diving towards the sea. This was the first indication available to the investigation that the aircraft had rolled into the descent, rather than pitched nose-down from a wings-level attitude. This aspect provided valuable assistance to the investigation, at a time when there was considerable doubt that the flight recorders would be recovered.

Following the recovery of the FDR, the sequence of events as described by the witness was proved to be accurate. This was further confirmed by the results of the experiments carried out in the flight simulator, as described at Para 1.18.2.

A considerable amount of research has been carried out into the use of hypnosis during criminal investigations. Similar research is being undertaken for its use in aircraft accident investigations. There are conflicting reports of the usefulness of the technique, as it has been shown scientifically that hypnosis rarely enhances memory. However, there is evidence that hypnotic interviews are most likely to reveal significant information when witnesses are genuinely motivated towards the use of the technique. This was the first occasion in which hypnosis had been applied in this country to assist an aircraft accident investigation, and the results were encouraging.

1.18.2 Pilot Performance Experiments in Flight Simulator.

It became apparent during the investigation that the check pilot had possibly simulated failures of all FAIs shortly after the aircraft was established in a steady climb. This would leave the pilot flying the aircraft with no direct attitude instrument reference, and commit him to fly the aircraft with no gyro attitude instrument, in an environment where there were no external visual references. Such a task, while difficult, should be within the capabilities of a properly trained pilot, providing the remaining instruments are functioning correctly. However, the rate of turn indicator in this aircraft was operating in the reverse sense. The effects on pilot performance under these demanding circumstances was unknown.

In order to obtain specific information on the difficulties of maintaining aircraft control under the described circumstances, a series of experiments was carried out in a flight simulator. The results of the experiments were then used to animate an aircraft image on the Bureau's computer graphics system in order to observe the flight paths in three dimensions and in real time.

The simulator used was a Boeing 707-338 model. It was configured with a similar instrument panel to that in VH-IWJ, except that the rate of turn indicator was a separate instrument with a considerably larger pointer. For the purpose of the exercise, a 7 channel pen recorder was installed, and modifications were made to enable the sense of the rate of turn indicator to be reversed as desired.

The program for the experiment was devised by the Bureau's human performance experts, in conjunction with flight recorder and simulator specialists. The pilots used were 9 qualified Boeing 707 pilots. They were each required to execute a take-off followed by a "16 West Maitland One" departure from Sydney, with the introduction of limited panel operation shortly before the required turn at 6 DME. The exercise was then repeated, but with the sense of the rate of turn indicator reversed at the point of introduction of the limited panel condition.

The results of the study showed that all of the pilots maintained adequate control of the aircraft when the rate of turn indicator was operating correctly. However, with the sense of this instrument reversed, 3 pilots lost control and "crashed" the simulator. In each case, control was lost after the commencement of the left turn, with the aircraft finally executing a steep turn to the right. The final impact was at an angle in excess of 50 degrees nose down, and at an airspeed in excess of 500 knots. None of the pilots made any attempt to reduce engine thrust, and all impacts were with climb thrust still applied.

The average time taken for the aircraft to descend from about 5000 feet to sea level was 12 seconds. In addition, 4 other pilots entered a right turn following their initial turn to the left. These pilots were able to retain control, and subsequently were able to turn again to the left. It was noted that all pilots who turned to the right did so an average of 6 seconds after commencing the planned turn to the left. This finding was of considerable interest, as it had been believed that with the turn indicator showing a right deflection when the left turn was commenced, the pilot would naturally apply more left bank input to achieve the desired result. It was therefore expected that if control were lost, it would involve an increasing bank to the left. The simulator experiments showed unequivocally that this was not the case.

2 ANALYSIS

2.1 General

The initial preparations for the flight were apparently normal. The unserviceabilities listed in the maintenance documentation relating to the rate of turn indicator and the altitude alerting system would not, in themselves, have affected the ability of the crew to safely conduct the flight. The take-off and initial climb also appeared to be normal. However, control of the aircraft was lost just over 2 minutes after take-off, as a turn, which should have taken the aircraft left through 129 degrees, was commenced.

This analysis evaluates the relevant areas of the witness, engineering and flight recorders evidence and examines the possible operational reasons for the loss of control and the subsequent descent into the sea.

2.2 The Aircraft

Appropriate maintenance documentation relating to the aircraft was in order, and all mandatory maintenance and inspections were recorded as having been carried out. There was no evidence that the aircraft was other than serviceable prior to the flight, with the exception of the altitude alerting system and the rate of turn indicator. The aircraft had operated satisfactorily with a defect in the rate of turn indicator for almost 12 months.

Despite the fact that the indicator was faulty, no effort had been made to positively alert the pilots to its continuing presence. This could have been achieved by the placing of a placard near the face of the instrument, or by the pulling and locking of the appropriate circuit breaker.

The examination of the wreckage recovered together with the information obtained from the FDR and CVR did not reveal any evidence to indicate that the aircraft was not capable of normal operation at the time of departure from Sydney. Both engines were operating at high rotational speeds at the time of impact, and it was considered that the circumstances of the accident were not consistent with those that might be expected with an engine related problem.

2.3 The Crew

Both pilots were suitably licenced and qualified to undertake the flight. Mr had considerable experience on the aircraft type both in the normal operating and training roles. Mr had substantial experience on the type as a co-pilot, although this was to be only his third flight while occupying the left control seat. On the previous occasions he had not been flying VH-IWJ.

With the exception of Mr 's disturbed sleep pattern on the evening of the flight, neither pilot had any known medical or psychological problem which might have affected their ability to safely operate the aircraft. The cause of Mr 's sleeping difficulty was not determined, but may have been related to some perceived stress, with reference to the importance of the flight on his future progress in the company. There was evidently nothing in his manner or appearance during the period before or on the night of the flight to suggest that he was not capable of performing his assigned duties.

There were insufficient human remains recovered to allow any detailed information to to be obtained from the autopsy examinations.

2.4 Meteorological Conditions

The sky in the area was relatively free of cloud, winds were light and visibility was unobstructed. There was no known turbulence or other meteorological phenomena that might have affected the aircraft. Weather conditions were therefore not considered to have had any bearing on the development of the accident.

2.5 The Accident Sequence

The evidence obtained from eye witnesses, recorded radar information and the FDR indicated that the aircraft was tracking in accordance with the assigned airways clearance. Shortly after commencing a turn at 6 DME, control of the aircraft was lost and a steep descent followed. Sudden loss of control of an aircraft under the circumstances was considered likely to have been caused by one of the following influences.

(a) Structural failure of the airframe

(b) Uncommanded elevator trim inputs.

(c) Sabotage

(d) Collision with another aircraft or object

(e) Pilot incapacitation

(f) Suicide

(g) Spatial disorientation

2.5.1 Structural Failure of the Airframe.

The aircraft type did not have any history of structural problems. VH-IWJ had been maintained in accordance with the approved schedules, and had flown a lower number of hours than its contemporaries in Australian operations.

Eye witness evidence indicated that the aircraft descended steeply but without noticeable movement about the longitudinal axis. The landing lights were visible, and formed the basis of this evidence. The lights were located on the front of the wing tip fuel tanks, thus it was apparent that neither wing had failed in flight. Portions of both elevators were recovered in the main area of floating wreckage, indicating that they had been attached to the airframe at or close to the point of impact. In addition, no sounds that could possibly be associated with an in-flight structural failure were detected on the CVR tape, nor was there any comment from the crew to indicate a sudden control problem. None of the components recovered showed any sign of failure other than by overload forces.

2.5.2 Uncommanded Elevator Trim Inputs.

There are known cases of aircraft accidents resulting from a situation known as "runaway elevator trim". Typically, the trim runs away to the full nose-up or full nose-down position, leading to loss of control and/or overload failure of the structure. None of these accidents have involved the Westwind type.

In the case in point, the most serious situation would result from a nose-down trim input. Such an input would result in a strong negative "g" acceleration as the aircraft pitched down. The FDR foil indicated that there was a progressive increase in positive "g" loadings, and eye witness evidence indicated that the aircraft rolled, rather than pitched, into the descent. In addition, the horizontal stabiliser jack was found to be in the mid-range of its travel. Again, no comments were recorded from the crew to indicate such a problem occurred.

2.5.3 Sabotage.

The most likely methods for any sabotage attempt were considered to be an explosive device or a toxic chemical or gas container concealed in the freight. The investigation disclosed no reason for any such attempt on this aircraft or crew, and the CVR tape did not record sounds of an on-board explosion or unusual comment from the crew. Forensic testing carried out by the NSW Police Department also failed to reveal any evidence to support a sabotage attempt.

2.5.4 Collision with Another Aircraft or Object.

The analysis of recorded radar information together with evidence from the various ATC personnel on duty indicated that no other aircraft was in the area at the time. The sounds of a bird or other object striking the aircraft with sufficient force to disrupt the structure would have been recorded on the CVR tape. No such noises were recorded.

2.5.5 Pilot Incapacitation.

Both pilots were apparently in good general health, although on the evening prior to the flight Mr had not slept as well as normal. It was considered possible that one of the pilots may have suffered a sudden illness or incapacity, such as a heart attack, and had slumped forwards onto the controls. Such a movement would result in a similar movement to a runaway trim situation, with a large negative "g" input. As previously mentioned, the "g" forces were positive, and there was no recorded comment or exclamation as might be expected if a crew member collapsed. The majority of Pel-Air pilots also believed that if either pilot slumped forward, the other had sufficient strength to pull him clear of the controls.

2.5.6 Suicide.

No evidence was found to suggest that either or both pilots had contemplated such an attempt.

2.6 Spatial Disorientation.

In the absence of any evidence to indicate that the loss of control was related to any of the previous considerations, it seems likely that the accident resulted from the crew losing their awareness of the attitude of the aircraft.

Spatial disorientation describes a situation in which a pilot fails to sense correctly the position, motion or attitude of his aircraft. It results from a conflict of information from his senses, primarily those of vision and balance. Alternatively, where there are insufficient visual cues, the information from the sense of balance is all that is available to determine orientation. The sense of balance is extremely unreliable and, depending on the circumstances of flight, may provide erroneous information to the pilot. If there is no visual means with which to cross-check the information from the balance senses, the pilot may be unaware that it is in error. His perception of the aircraft orientation in space may thus be incorrect, and he will not be aware that this is so.

Both pilots were qualified to operate the aircraft under Instrument Meteorological Conditions. The night was dark, and there would have been no visible horizon as the aircraft tracked out to sea. Under these conditions the crew would have been required to monitor and control the attitude of the aircraft solely by reference to the flight instruments. The aircraft had a comprehensive array of instruments, including two FAIs on the left panel and one on the right. On a routine flight it would be expected that if both indicators on the left side failed, or if the pilot had difficulty with control, the pilot in the right seat would monitor the situation or assume control if necessary. The FAIs were powered from separate sources, and the simultaneous failure of all three was extremely unlikely. No evidence was found to indicate that any of the FAIs had failed for technical reasons.

It is difficult to conceive how two experienced pilots would lose control of the aircraft in normal flight conditions if all the instruments usually available for attitude control were functioning properly.

2.6.1 Simulation of Flight Instrument Unserviceability.

Information recovered from the CVR indicated that soon after the required checks following take-off had been completed and the aircraft was established in a normal climb, the check pilot stated his intention to simulate an emergency instrument situation. The simulation was probably intended as a test of the ability of Mr to operate the aircraft under limited instrument conditions. Evidence obtained from other company pilots indicated that Mr was known to introduce such an exercise by failing both FAIs on the left instrument panel. This would require the pilot being checked to assess the attitude of the aircraft by integrating the information presented by the remaining flight instruments, in order to give a mental picture of the position of the aircraft with reference to the natural horizon. To counter any tendency on the part of the pilot to glance at the FAI on the right instrument panel for additional guidance, Mr was known to cover this instrument, or to turn the lighting down on that side of the cockpit. Although this ensured that the pilot flying the aircraft had no single attitude reference instrument, it also deprived Mr of an instant check of aircraft attitude. If he had adopted such a procedure on this occasion, he lost the ability to readily monitor Mr 's performance of the task, because of the lack of a natural or artificial horizon reference.

If the limited panel situation had been simulated as discussed above, Mr would have had to make use of the rate of turn indicator in order to assess the bank angle of the aircraft during the turn. Although he had recently been informed by another company pilot of the defect in the instrument, it was likely that he inadvertently overlooked it under the high workload involved as he concentrated on the handling of the aircraft. It was apparent that the loss of control occurred shortly after the planned turn to the left had been commenced, and followed a steep bank to the right. It was likely that neither pilot was aware of the attitude of the aircraft until it had reached an extreme point, possibly at or about the inverted position and with the nose well below the horizontal. From this position, there was evidently insufficient height remaining in which the pilots could effect a recovery.

3. CONCLUSIONS

Findings.

1. The pilots were correctly licenced and were suitably experienced and qualified to undertake the flight.

2. There was no evidence that either pilot suffered any sudden illness or incapacity which might have affected his ability to safely control the aircraft.

3. The aircraft had been maintained in accordance with the approved schedules, and there was nothing to suggest that it was not capable of normal operation at the time of departure from Sydney Airport.

4. The weight and centre of gravity of the aircraft were estimated to be within the limits specified in the approved Flight Manual.

5. The provision of air traffic control services was not a factor in the accident.

6. There were no meteorological conditions that might have contributed to the accident.

7. The aircraft was technically rendered un-airworthy by virtue of a defect in the rate of turn indicator, which formed part of the FAI on the left hand side instrument panel. The presence of the defect had been known for almost 12 months, and all attempts to rectify the deficiency had been unsuccessful. The operating company had not made application to have the defect incorporated into the approved Permissible Unserviceability Schedule.

8. The operating company had made no effort to alert pilots to the continuing presence of the above defect, by placarding or removing the electrical power supply to the instrument.

9. The presence of the defect did not compromise the ability of the crews to operate the aircraft safely under normal conditions.

10. The pilot in command intended to use the flight to assess the performance of the co-pilot, who was being considered for up-grading to command status.

11. The pilot in command was known to simulate emergency instrument flight conditions while checking company pilots. These simulations took the form of failures to the FAIs on the left instrument panel, and the masking of the indicator on the right by covering or the removal of instrument lighting.

12. It was likely that on this occasion that the simulated failures referred to above were given shortly before the aircraft reached a position of 6 DME from Sydney. At this time the pilot in command had no external reference by which to monitor the attitude of the aircraft in relation to the horizon.

13. Shortly after commencing a planned turn to the left at a height of about 5000 feet, the aircraft entered a rapid turn to the right and rolled, probably to a nose-down inverted position, before entering a steep descent.

14. The pilots did not recover control of the aircraft before impact with the water.

15. Experiments conducted in a simulator confirmed that the observed loss of control was typical of that which could occur when the pilot had no single attitude reference instrument, and at a time when the rate of turn indicator was operating in the incorrect sense.

Relevant Events and Factors.

1. There was a known malfunction of the rate of turn indicator.

2. The pilot in command possibly simulated simultaneous failures of all three flight attitude indicators.

3. There were no external references by which the crew could assess the attitude of the aircraft.

4. A loss of control of the aircraft occurred at a height of about 5000 feet.

5. The crew did not recover control of the aircraft prior to impact with the sea.

4. SAFETY RECOMMENDATIONS

4.1 When the likely circumstances of the accident had been established, the following recommendation was made to the Department of Aviation:

"That consideration should be given to prohibiting comprehensive simulated flight instrument failures while training and checking at night and in non-Visual Meteorological Conditions."

The Department of Aviation subsequently advised that the recommendation had been accepted, and appropriate steps had been undertaken to alert the aviation industry.

4.2 Because of the difficulty in determining the final flight path and subsequently locating the wreckage of the aircraft, due in part to the failure of the Underwater Locator Beacon on the Flight Data Recorder, and the lack of recorded primary radar information, the following recommendations were also made to the Department of Aviation:

(a) "That consideration should be given to requiring the fitment of Underwater Locator Beacons to Cockpit Voice Recorders as well as to Flight Data Recorders in aircraft required to carry such devices."

(b) "That consideration should be given to the provision of suitable equipment to permit the recording of primary radar information from Terminal Area and Route Surveillance Radar installations."

ICAO Note.— Names of personnel were deleted. Figure 1 and Appendices A to C were not reproduced.

ICAO Ref.: 333/85

ICAO TECHNICAL PUBLICATIONS

The following summary gives the status, and also describes in general terms the contents of the various series of technical publications issued by the International Civil Aviation Organization. It does not include specialized publications that do not fall specifically within one of the series, such as the Aeronautical Chart Catalogue *or the* Meteorological Tables for International Air Navigation.

International Standards and Recommended Practices are adopted by the Council in accordance with Articles 54, 37 and 90 of the Convention on International Civil Aviation and are designated, for convenience, as Annexes to the Convention. The uniform application by Contracting States of the specifications contained in the International Standards is recognized as necessary for the safety or regularity of international air navigation while the uniform application of the specifications in the Recommended Practices is regarded as desirable in the interest of safety, regularity or efficiency of international air navigation. Knowledge of any differences between the national regulations or practices of a State and those established by an International Standard is essential to the safety or regularity of international air navigation. In the event of non-compliance with an International Standard, a State has, in fact, an obligation, under Article 38 of the Convention, to notify the Council of any differences. Knowledge of differences from Recommended Practices may also be important for the safety of air navigation and, although the Convention does not impose any obligation with regard thereto, the Council has invited Contracting States to notify such differences in addition to those relating to International Standards.

Procedures for Air Navigation Services (PANS) are approved by the Council for world-wide application. They contain, for the most part, operating procedures regarded as not yet having attained a sufficient degree of maturity for adoption as International Standards and Recommended Practices, as well as material of a more permanent character which is considered too detailed for incorporation in an Annex, or is susceptible to frequent amendment, for which the processes of the Convention would be too cumbersome.

Regional Supplementary Procedures (SUPPS) have a status similar to that of PANS in that they are approved by the Council, but only for application in the respective regions. They are prepared in consolidated form, since certain of the procedures apply to overlapping regions or are common to two or more regions.

The following publications are prepared by authority of the Secretary General in accordance with the principles and policies approved by the Council.

Technical Manuals provide guidance and information in amplification of the International Standards, Recommended Practices and PANS, the implementation of which they are designed to facilitate.

Air Navigation Plans detail requirements for facilities and services for international air navigation in the respective ICAO Air Navigation Regions. They are prepared on the authority of the Secretary General on the basis of recommendations of regional air navigation meetings and of the Council action thereon. The plans are amended periodically to reflect changes in requirements and in the status of implementation of the recommended facilities and services.

ICAO Circulars make available specialized information of interest to Contracting States. This includes studies on technical subjects.

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