ICAO CIRCULAR – CIRCULAIRE OACI – CIRCULAR OACI

Cir. 262-AN/156

1996

Aircraft Accident Digest
Recueil d'accidents d'aviation
Recopilación de accidentes de aviación

No. - N° - Núm. 36

1989

Approved by the Secretary General and published under his authority
Approuvé par le Secrétaire général et publié sous son autorité
Aprobada por el Secretario General y publicada bajo su responsabilidad

INTERNATIONAL CIVIL AVIATION ORGANIZATION
ORGANISATION DE L'AVIATION CIVILE INTERNATIONALE
ORGANIZACIÓN DE AVIACIÓN CIVIL INTERNACIONAL

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1/96

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 6.12 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.

AVANT-PROPOS

Généralités

1. Le recueil d'accidents d'aviation a pour but de communiquer à tous les États contractants certains renseignements sur les rapports d'accidents. La publication du recueil a commencé en 1951. Au cours des années, les États ont manifesté à plusieurs reprises leur intérêt pour le recueil, parce qu'il constitue non seulement une source précieuse d'information pour la prévention des accidents, mais aussi une aide de formation pour les enquêteurs et un manuel éducatif pour les écoles techniques.

Sélection des accidents

2. Le recueil contient des rapports d'accidents choisis par le Secrétariat parmi ceux communiqués par les États. Ce choix repose sur les critères suivants:

a) intérêt du rapport pour la prévention des accidents;

b) utilisation fructueuse de techniques d'enquête utiles ou efficaces;

c) conformité aux spécifications de l'Annexe 13, y compris celles concernant la présentation du rapport final.

Le présent recueil ne saurait être considéré comme représentatif, du point de vue statistique, de la répartition des accidents dans le monde.

Normes de rédaction

3. Les rapports finals sont généralement publiés tels qu'ils sont reçus. Par conséquent, ils peuvent présenter certaines différences par rapport aux normes OACI de rédaction. Certains rapports particulièrement longs sont abrégés par l'omission de renseignements redondants, d'appendices, de pièces jointes ou de schémas. De légères modifications sont parfois apportées à la présentation, ainsi qu'à la terminologie, afin d'assurer la conformité avec les dispositions de l'Annexe 13.

Coopération des États

4. Les États sont invités à envoyer à l'OACI des rapports finals conformes aux critères de 6.12 de l'Annexe 13. Les rapports doivent être rédigés dans l'une des langues de travail de l'OACI et présentés comme il est indiqué dans l'Appendice à l'Annexe 13.

Publication des recueils d'accidents

5. Le recueil est publié une fois par an et comprend des comptes rendus d'accidents et d'incidents survenus au cours d'une année.

PREÁMBULO

Consideraciones de carácter general

1. El objeto de la Recopilación de accidentes de aviación es transmitir información sobre accidentes a los Estados contratantes. La publicación de esta serie se inició en 1951. Con el transcurso de los años, los Estados han reiterado su interés por la Recopilación, puesto que ésta constituye no sólo una valiosa fuente de datos para la prevención de accidentes, sino también una ayuda para la formación de investigadores, y sirve asimismo de material didáctico para las escuelas técnicas.

Selección de accidentes

2. La Recopilación contiene informes y accidentes elegidos por la Secretaría de entre los que envían los Estados. La selección se basa en los criterios siguientes:

a) su aportación a la prevención de accidentes; o

b) el empleo con éxito de técnicas de investigación consideradas útiles o eficaces; y

c) el cumplimiento del Anexo 13 y también la forma de presentación del Informe final.

Desde el punto de vista estadístico, la Recopilación no debe considerarse representativa de la distribución mundial de los accidentes.

Forma habitual de presentación

3. Usualmente los informes finales se publican tal como se reciben. Por eso es posible que existan algunas discrepancias en relación con la forma habitual de presentación de la OACI. A veces, los informes extensos se abrevian eliminando información oficiosa, apéndices, adjuntos o diagramas. Se pueden introducir pequeños cambios en la presentación y la terminología con miras a dar cumplimiento al Anexo 13.

Cooperación de los Estados

4. Se alienta a los Estados a que transmitan a la OACI únicamente los informes finales que satisfagan los criterios señalados en el párrafo 6.12 del Anexo 13. Los informes deben venir redactados en uno de los idiomas de trabajo de la OACI y del modo indicado en el Apéndice al Anexo 13.

Publicación de las recopilaciones

5. Las recopilaciones de accidentes se publican anualmente y contienen accidentes e incidentes ocurridos en el transcurso del año a que se refieren.

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No. 1

Boeing 737-400, G-OBME, accident near Kegworth, Leicestershire, United Kingdom on 8 January 1989. Aircraft Accident Report 4/90 released by the Air Accidents Investigation Branch, Department of Transport, United Kingdom

SYNOPSIS

G-OBME left Heathrow Airport for Belfast at 1952 hrs with 8 crew and 118 passengers (including 1 infant) on board. As the aircraft was climbing through 28,300 feet the outer panel of one blade in the fan of the No 1 (left) engine detached. This gave rise to a series of compressor stalls in the No 1 engine, which resulted in airframe shuddering, ingress of smoke and fumes to the flight deck and fluctuations of the No 1 engine parameters. Believing that the No 2 engine had suffered damage, the crew throttled that engine back and subsequently shut it down. The shuddering caused by the surging of the No 1 engine ceased as soon as the No 2 engine was throttled back, which persuaded the crew that they had dealt correctly with the emergency. They then shut down the No 2 engine. The No 1 engine operated apparently normally after the initial period of severe vibration and during the subsequent descent.

The crew initiated a diversion to East Midlands Airport and received radar direction from air traffic control to position the aircraft for an instrument approach to land on runway 27. The approach continued normally, although with a high level of vibration from the No 1 engine, until an abrupt reduction of power, followed by a fire warning, occurred on this engine at a point 2.4 nm from the runway. Efforts to restart the No 2 engine were not successful.

The aircraft initially struck a field adjacent to the eastern embankment of the M1 motorway and then suffered a second severe impact on the sloping western embankment of the motorway.

39 passengers died in the accident and a further 8 passengers died later from their injuries. Of the other 79 occupants, 74 suffered serious injury.

The cause of the accident was that the operating crew shut down the No 2 engine after a fan blade had fractured in the No 1 engine. This engine subsequently suffered a major thrust loss due to secondary fan damage after power had been increased during the final approach to land.

The following factors contributed to the incorrect response of the flight crew:

1. The combination of heavy engine vibration, noise, shuddering and an associated smell of fire were outside their training and experience.

2. They reacted to the initial engine problem prematurely and in a way that was contrary to their training.

3. They did not assimilate the indications on the engine instrument display before they throttled back the No 2 engine.

4. As the No 2 engine was throttled back, the noise and shuddering associated with the surging of the No 1 engine ceased, persuading them that they had correctly identified the defective engine.

5. They were not informed of the flames which had emanated from the No 1 engine and which had been observed by many on board, including 3 cabin attendants in the aft cabin.

31 Safety Recommendations were made during the course of this investigation.

1. FACTUAL INFORMATION

1.1 History of the flight

The aircraft was engaged on a double shuttle between London Heathrow Airport and Belfast Aldergrove Airport. It landed at Heathrow at 1845 hrs on completion of the first shuttle flight and took off again for Belfast at 1952 hrs, with the first officer handling the aircraft. After take-off the aircraft climbed initially to 6,000 feet where it levelled-off above a layer of stratocumulus cloud for 2 minutes, before receiving clearance to climb to flight level (FL) 120. Soon afterwards, at 1958 hrs, clearance was passed to climb to FL 350 on a direct track to the very high frequency omni-range beacon (VOR) at Trent.

At 2005.05 hrs, as the aircraft was climbing through FL283 some 20 nm south-south-east of East Midlands Airport, the crew experienced moderate to severe vibration and a smell of fire. The area microphone for the cockpit voice recorder (CVR) picked up a sound of vibration or 'rattling' at this time and the flight data recorder (FDR) showed significant fluctuations in lateral and longitudinal accelerations. There was no fire warning or any other visual or aural warning on the flight deck. The commander stated afterwards that he saw and smelt air conditioning smoke. The first officer later remembered only a strong smell of burning. Replay of the FDR showed that severe vibration had occurred in the No 1 (left) engine at this time, accompanied by marked fluctuations in fan speed (N1), a rise in exhaust gas temperature (EGT) and low, fluctuating, fuel flow.

The commander took control of the aircraft and disengaged the autopilot. He later stated that he looked at the engine instruments but did not gain from them any clear indication of the source of the problem. He also later stated that he thought that the smoke and fumes were coming forward from the passenger cabin, which, from his appreciation of the aircraft air conditioning system, led him to suspect the No 2 (right) engine. The first officer also said that he monitored the engine instruments and, when asked by the commander which engine was causing the trouble, he said 'IT'S THE LE ... IT'S THE RIGHT ONE.', to which the commander responded by saying 'OKAY, THROTTLE IT BACK'. The autothrottle was then disengaged and the No 2 engine was throttled back. The first officer later had no recollection of what it was he saw on the engine instruments that led him to make his assessment. The commander's instruction to throttle back was given some 19 seconds after the onset of the vibration when, according to the FDR, the No 2 engine was operating with steady engine indications. During the 11 seconds that elapsed between the disengagement of the autopilot and the throttling back of the No 2 engine, the aircraft rolled slowly to the left through 16 degrees but the commander made no corrective movement of aileron or rudder.

Within 1 to 2 seconds of the closure of the No 2 throttle the aircraft rolled level again, the fluctuations in lateral and longitudinal accelerations ceased, the No 1 engine fan speed settled at a level 3% below its previous stable speed, and the EGT stabilised at 50°C above its previous level. These engine parameters remained fairly stable for a further minute until the commander reduced power on that engine for the descent. However, the indicated vibration remained at maximum and the indicated fuel flow behaved erratically. The commander later stated that the action of closing the No 2 engine throttle reduced the smell and the visual signs of smoke and that he remembered no continuation of the vibration after the No 2 throttle was closed.

Immediately after throttling back the No 2 engine, the first officer advised London Air Traffic Control (LATCC) that they had an emergency situation which looked like an engine fire. The commander then ordered the first officer: 'SHUT IT DOWN'. This order was given 43 seconds after the onset of the vibration but its execution was delayed when the commander said 'SEEMS TO BE RUNNING ALRIGHT NOW. LETS JUST SEE IF IT COMES IN'. The shutdown was further delayed as the first officer responded to radio messages from LATCC which advised the crew of the aircraft's position and asked which alternate airfield they wished to go to. The first officer said that it looked as if they would take it to Castle Donington (East Midlands Airport) but LATCC were to stand by. At about this time a flight attendant used the cabin address system to advise the passengers to fasten their seat belts. The first officer then told the commander that he was about to start the 'Engine Failure and Shutdown' checklist, saying at the same time 'SEEMS WE HAVE STABILISED. WE'VE STILL GOT THE SMOKE'. Again, action on the checklist was suspended as the commander called British Midland Airways (BMA) Operations at East Midlands Airport to advise his company of the situation. 2 minutes 7 seconds after the start of the vibration and during a short pause in radio communications with BMA Operations, the fuel cock (start lever) of the No 2 engine was closed and the auxiliary power unit (APU) was started. Shortly afterwards BMA Operations transmitted to the aircraft: 'DIVERT TO EAST MIDLANDS PLEASE'.

The commander later recollected that, as soon as the No 2 engine had been shut down, all evidence of smell and smoke cleared from the flight deck, and this finally convinced him that the action he had taken was correct. Shortly afterwards power was further reduced on the No 1 engine, which continued to operate at reduced power with no symptoms of unserviceability other than a higher than normal level of indicated vibration and increased fuel flow. This high level of vibration continued for a further 3 minutes and then fell progressively until it reached a level of 2 units on the cockpit indicator, still a little higher than normal. After the accident, the commander stated that during the remainder of the flight the indications that he had from the engine instruments, or any other source, were such as to indicate that the emergency had been successfully concluded and that the No 1 engine was operating normally.

In the cabin, the passengers and the cabin attendants heard an unusual noise accompanied by moderate to severe vibration. Some passengers were also aware of what they described as smoke, but none could describe its colour or density. They described the smell of burning as 'rubber', 'oil' and 'hot metal'. Many saw signs of fire from the left engine, which they described variously as 'fire', 'torching' or 'sparks'. Several of the cabin attendants described the noise as a low, repetitive thudding, 'like a car backfiring', and one described how the shuddering shook the walls of the forward galley. The three flight attendants in the rear of the cabin saw evidence of fire from the No 1 engine, and two of them briefly saw light coloured smoke in the cabin. Soon after the No 2 engine was shut down the commander called the flight service manager (FSM) to the flight deck and asked him 'DID YOU GET SMOKE IN THE CABIN BACK THERE?', to which the FSM replied 'WE DID, YES'. The commander then instructed the FSM to clear up the cabin and pack everything away. About one minute later the FSM returned to the flight deck and said 'SORRY TO TROUBLE YOU . . THE PASSENGERS ARE VERY VERY PANICKY'. The commander then broadcast to the passengers on the cabin address system that there was trouble with the right engine which had produced some smoke in the cabin, that the engine was now shut down and that they could expect to land at East Midlands Airport in about 10 minutes. The flight attendants who saw signs of fire on the left engine later stated that they had not heard the commander's reference to the right engine. However, many of the passengers who saw fire from the No 1 engine heard and were puzzled by the commander's reference to the right engine, but none brought the discrepancy to the attention of the cabin crew, even though several were aware of continuing vibration. The smell of smoke, however, had dissipated by the time the commander made this announcement.

The No 2 engine was shut down approximately 5 nm south of East Midlands Airport. Having cleared the aircraft to turn right and descend to FL 100, London ATC passed control to Manchester ATC, who passed headings to steer for the aircraft to descend to the north of East Midlands Airport (EMA) and to fly to the centreline of the localizer of the instrument landing system (ILS) for runway 27. During the descent the commander did not re-engage the autopilot but flew the aircraft manually, whilst the first officer dealt with radio communications. Flight deck workload remained high as the first officer obtained details of the actual weather at East Midlands and attempted without success to programme the flight management system to display the landing pattern at East Midlands. This last activity engaged the first officer's attention for 2 minutes. At 2012.28 hrs the commander attempted to review their situation, saying 'NOW WHAT INDICATIONS DID WE ACTUALLY GET (IT) JUST RAPID VIBRATIONS IN THE AEROPLANE - SMOKE ...'. His discussion with the first officer was then interrupted by ATC messages passing a new radar heading, further descent clearance to FL40 and instructions for the aircraft to change radio frequency to East Midlands (Castledon) approach control. As soon as contact was established on the new frequency the first officer began to read the one-engine inoperative descent and approach checklist. Radio calls again interrupted this activity when the Castledon approach controller asked the commander to make a test call to the aerodrome fire service, which he did, but received no response. The approach checklist was finally completed at 2017.33 hrs, when the aircraft was 15 nm from touchdown, descending through 6,500 feet above mean sea level (amsl). One minute later the commander accepted a new radar vector of 220° to take the aircraft south of the extended runway centreline in order to increase his distance from touchdown, and shortly afterwards called for the wing flaps to be selected to 1°. Throughout the descent there were distractions from a small number of other aircraft making radio calls on the same frequency as that being used by G-OBME.

When the aircraft was 13 nm from touchdown on this new heading, and descending to 3,000 feet amsl, ATC advised a right turn to bring the aircraft back to the centreline. At 2020.03 hrs, during this turn, power was increased on the No 1 engine to level the aircraft momentarily at 3,000 feet and maximum indicated vibration was again recorded on the FDR. The aircraft was then cleared to descend to 2000 feet and the commander began a slow descent, calling successively for 2° and then 5° of flap. After joining the centreline, at 2000 feet above ground level (agl), the commander called for the landing gear to be lowered and, as he passed the outer marker at 4.3 nm from touchdown, called for 15° of flap. One minute later, at 2023.49 hrs, when the aircraft was 2.4 nm from touchdown at a height of 900 feet agl, there was an abrupt decrease in power from the No 1 engine. The commander called immediately for the first officer to relight (ie restart) the other engine and the first officer attempted to comply. The commander then raised the nose of the aircraft in an effort to reach the runway. 17 seconds after the power loss the fire warning system operated on the No 1 engine and 7 seconds later the ground proximity warning system (GPWS) glideslope warning sounded and continued with increasing repetitive frequency as the aircraft descended below the glidepath. The commander ordered the first officer not to carry out the fire drill. At 2024.33 hrs the commander broadcast a crash warning on the cabin address system using the words 'PREPARE FOR CRASH LANDING' (repeated). 2 seconds later, as the airspeed fell below 125 kts, the stall warning stick shaker[1] operated, and continued to operate until the

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[1] Stick shaker. An artificial stall warning device that causes both control columns to vibrate when the airspeed falls within not less than 7% of the actual stall speed.

aircraft struck the ground at 2024.43 hrs. The last airspeed recorded on the FDR was 115 kts. No power became available from the No 2 engine before the aircraft struck the ground.

The initial ground impact was in a nose-high attitude on level ground just to the east of the M1 motorway. The aircraft then passed through trees and suffered its *second and major impact 70 metres to the west and 10 metres lower*, on the western (*ie* northbound) carriageway of the M1 motorway and the lower part of the western embankment. The fuselage was extensively disrupted, and the aircraft came to rest entirely on the wooded western embankment approximately 900 metres from the threshold of runway 27 and displaced 50 metres to the north of the extended runway centreline.

Several of the passengers described heavy vibration immediately prior to the impact and one passenger, in the rear of the aircraft, described the vibration as being severe enough to open the overhead lockers and cause them to spill contents. Passengers in the rear of the aircraft described two distinct impacts; those in the front appeared only to have been aware of the final impact.

Ground witnesses who saw the final approach saw clear evidence of fire associated with the left engine. The intake area of the engine was filled with yellow/orange fire, and flames were observed streaming aft from the nacelle, pulsating in unison with 'thumping noises'. Metallic 'rattling' was also heard, and flaming debris was seen falling from the aircraft.

After the aircraft crashed, a BMA engineer entered the flight deck and switched off the main battery switch and the standby power switch. He later returned to the flight deck and switched off the engine ignition (engine start switches) and the fuel booster pumps. The engine start levers (fuel valves) were found in the cutoff position. No witness was found who could testify to having moved them.

1.2 Injuries to Persons

	Crew	*Passengers*	*Others*
Fatal	nil	47	Nil
Serious	7	66 + 1 infant	Nil
Minor/none	1	4	

5 firemen suffered minor injuries during the rescue operation.

1.3 Damage to aircraft

G-OBME suffered severe impact damage and the fuselage broke into 3 main sections (Fig 1). The nose section travelled the greatest distance up the western embankment of the M1, the centre-section remained upright with the wings attached and the tail-section buckled over, and to the right of, that section of fuselage just aft of the wing.

Both engines were found at their wing stations, although they had suffered ground impact damage. Most of the components which had separated were found around the impact site. Several small pieces of the No 1 engine were recovered from a site about 3 kilometres to the east, under the final flight path.

1.4 Other damage

During the crash sequence the rear fuselage underside and main landing gear of the aircraft scraped the surface off a small area of a grass field next to the eastern embankment of the motorway. The aircraft then demolished a 10 metre section of wooden fencing at the crest of the eastern embankment, before cutting a 40 metre swathe through the tops of trees growing on the embankment.

As the aircraft descended across the carriageways it destroyed one central lamp standard and a detached landing gear leg struck and deformed the central reservation barrier. The aircraft then slid up the western embankment, destroying trees over an area approximately 40 metres square.

1.5 Personnel information

1.5.1 *Commander:* Male, aged 43 years

Licence: Airline Transport Pilot's Licence first issued 9 August 1977, valid until 8 August 1997

Aircraft ratings: Auster, Dakota/C47, BAC 1-11, Viscount, DC-9, F 27, Boeing 737 Series 200, 300 and 400

Medical certificate: Class One issued 24 August 1988 with no limitations, valid until 31 March 1989

Instrument rating: Valid until 15 November 1989

Last base check: 16 October 1988

Last route check: 12 November 1988

Last emergencies check: 26 April 1988

Flying experience:
Total all types: 13,176 hours
Total on B737: 763 hours
Total last 90 days: 112 hours
Total last 28 days: 12 hours

Duty time: On leave from 17 December 1988. On duty 1430 hrs 8 January 1989

The commander underwent initial flying training at The London School of Flying in 1964/65 before joining BMA in 1966. He was employed as a first officer until he passed a command course in 1974, and then as a captain successively on Viscount, F27 and DC9 aircraft until 1987. He completed a conversion course to the Boeing 737 Series 300 on 13 December 1987 and a further short course on the Series 400 aircraft on 17 October 1988. He had flown 23 hours on the Series 400 aircraft.

1.5.2 *First Officer* Male, aged 39 years

Licence: Airline Transport Pilot's Licence first issued 12 August 1986 and valid until 11 August 1996

Aircraft ratings: PA 28, Cessna 402B, 402C and 404, Shorts SD 330 Series100 and 200, Shorts SD 360 Series 100 and 200, Boeing 737 Series 200, 300 and 400

Medical certificate: Class One issued 25 August 1988 with no limitations, valid until 31 March 1989

Instrument rating: Valid until 13 August 1989

Last base check: 22 December 1988

Last route check: 5 November 1988

Last emergencies check: 20 July 1988

Flying experience:
Total all types: 3,290 hours
Total on B737: 192 hours
Total last 90 days: 104 hours
Total last 28 days: 37 hours

Duty time: On duty 1200 hours 8 January 1989 (positioning to London / Heathrow from Belfast.)

The first officer underwent flying training at Simulated Flight Training at Hurn Airport in 1983. He was then employed by several independent public air transport companies before joining BMA in 1988, where he was initially employed as a first officer on the Shorts SD 360. He received conversion training on the Boeing 737-300 from his company during June and July 1988. He was checked as competent to act as a first officer on the B737 Series 300 on 28 July 1988 and on the B737 Series 400 on 17 October 1988. He had flown 53 hours on the Series 400 aircraft.

* *1.5.3* *Cabin attendants (listed in order of joining BMA)*

1.6 Aircraft information

1.6.1 *Leading particulars*

Type:	Boeing 737 Series 400
Constructor's number:	23867
Date of Manufacture:	1988
Certificate of Registration:	Registered in the name of British Midland Airways Ltd.
Certificate of Airworthiness:	Issued on 3 November 1988 in the Transport Category (Passenger) and valid until 2 November 1989.
Total airframe hours:	521
Engines (2):	CFM 56-3C high by-pass turbofan engines No 1 Serial No:- 725-127 No 2 Serial No:- 725-130
Maximum weight authorised for take-off:	64,636 kg (142,496lb)
Actual take-off weight:	49,940 kg (110,098 lb)
Maximum weight authorised for landing:	54,884 kg (120,997 lb)
Estimated weight at the time of the accident:	48,900 kg (107,805 lb)

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*ICAO Note.— Section 1.5.3 was not reproduced.

Estimated fuel remaining at the time of the accident:	4,210 kg (9,281 lb)
Centre of gravity (CG) limits at accident weight:	8-27.6% mean aerodynamic chord (MAC)
CG at time of accident:	15.7% MAC

*1.6.2 *Description of engines*

*1.6.3 *Engine instrument system (EIS).*

*1.6.4 Airborne vibration monitoring (AVM) system

The AVM system continuously displays engine vibration levels via the indicators on the secondary EIS. This information is also output to the FDAU for transmission to the digital flight data recorder and stored as 'peak per flight' values in the non-volatile memory of the AVM module in the electronics bay.

*1.6.5 *Engine fire and overheat detection system*

*1.6.6 *Air conditioning system*

*1.6.7 *Cabin floor structure*

*1.6.8. *Seats*

*1.6.9 *Overhead stowage bins*

*1.6.10 *Maintenance records*

1.7 Meteorological information

1.7.1 *General situation*

The route from London to East Midlands lay within a moist west-south-westerly airstream, with a marked temperature inversion around 3,000 feet. The 0°C isotherm was at 10,000 ft. There was scattered stratus and stratocumulus cloud

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**ICAO Note.*— Sections 1.6.2 to 1.6.10 were not reproduced.

between 1,000 feet and 3,500 feet over the southern part of the route and a small probability of scattered stratocumulus up to 6,500 feet to the north, with thin patches of altocumulus/altostratus between 14,000 and 17,000 feet.

1.7.2 Actual weather conditions

The weather at Heathrow at 1950 hrs was reported as: wind velocity 230°/6 kts; visibility 6,000 metres; cloud 8 oktas stratus, base 500 feet; temperature +9° C; dew point +9° C; occasional light rain.

The actual weather at East Midlands Airport, reported to the pilot by ATC at 2011 hrs was: wind velocity 250°/10 kts; visibility 10 km; cloud 7 oktas, base 1,700 feet; temperature +9° C; QNH 1018.

1.8 Aids to navigation

A non-directional locator beacon (NDB), transmitting on 353.5 MHz and coded EME, was situated at the outer marker for runway 27 at East Midlands Airport, 4.3 nm from touchdown. The height of the 3° glideslope at the beacon was 1,710 feet amsl. Localizer and glidepath guidance for aircraft landing on runway 27 was provided by an instrument landing system (ILS); the localizer frequency was 109.9 MHz and the coding was I-EME. The NDB and the ILS were checked after the accident and found to be operating normally.

After the commander declared an emergency, the aircraft was given radar guidance from Manchester ATC and later East Midlands approach control for it to intercept the localizer for runway 27 at 6 nm from touchdown.

1.9 Communications

All communications were on very high frequency (VHF) radio and were satisfactory. Tape recordings were available of all frequencies used during the flight.

1.10 Aerodrome information

East Midlands Airport was a licensed public transport aerodrome constructed and equipped to international standards and operated by East Midlands International Airport plc. Runway 27 had a landing direction of 273° M, a threshold elevation of 280 feet amsl and a landing distance available of 2,280 metres. It had high intensity approach lights, with 5 crossbars, extending for 900 metres from the landing threshold; and low intensity centreline lighting, with one crossbar, extending for 420 metres. High intensity green lights with wing bars illuminated the threshold. Precision approach path indicators were installed for a 3° glideslope. All these lights were illuminated at the time of the accident.

The approach to runway 27 was over level terrain and passed over the M1 motorway, 1500 metres from touchdown. The southern edge of the village of Kegworth lay beneath the approach path to the east of the motorway.

1.11 Flight recorders

1.11.1 Flight Data Recorder (FDR)

The aircraft was fitted with a Sundstrand Universal Flight Data Recorder (UFDR) with a recording duration of 25 hours on magnetic (kapton) tape, and a Teledyne flight data acquisition unit (FDAU). A total of 63 parameters and 90 discrete events were recorded. In addition, the FDAU was equipped with a computer type 3½ inch 'floppy' disc which recorded 'snapshots' of routine information and data associated with specific exceedances. The FDR was located in the rear passenger cabin above the cabin roof, in line with the rear passenger exits.

The UFDR takes flight data into one of two internal memory stores, each holding about one second of data. When one memory store is full, the data flow is switched to the other store. While the data is being fed to this other store, the tape is rewound and the previous second of data is checked. A gap is left on the tape and the data in the first store is then written to the tape, and the first memory store emptied. This whole 'checkstroke' operation takes much less than one second to complete so that once the other store is full, data is switched back to the first store, and the other store is written to tape using the 'checkstroke' operation again to check its data. The procedure is then repeated.

Thus the UFDR tape is not running continuously. The tape first accelerates from stationary to 6 inches per second to read the previous data block, leaves an inter-record gap and then writes the new data block. The tape then slows and rewinds ready to begin the next 'checkstroke' operation. A total of 0.48 inches of tape is used to record one block of data and inter-record gap.

Data is formatted by the FDAU into one second subframes, each subframe begins with a synchronisation code, and is followed by the other parameters in a 64 word set format. The start of a block of data stored in the internal memory may not coincide with the start of a subframe, so when a block is recorded onto tape it is preceded by 'pre-amble' data bits and followed by 'post-amble' data bits. These bits of data are recognised during replay and removed, producing a continuous datastream. The start of a frame is identified from the synchronisation code.

When power is lost from the recorder, the data held in the volatile memory which has not been recorded on the tape is lost. As can be seen from the way in which data is temporarily stored on this UFDR and then recorded, this can mean that up to 1.2 seconds of data may be lost just before impact. Analysis of the raw signal on the UFDR tape from ME showed that the recorder had completed writing the contents of one memory store to tape, and this stopped at word 30 subframe 2. It was not possible, in this case, to know exactly how much data had been lost, and obviously as this was the last information prior to impact, such data could have been important to the investigation.

Where the parameters recorded were those presented to the crew on the EIS system, with the exception of vibration and engine oil temperature, the UFDR derived its information from the EIS. Each parameter from the EIS was treated in a similar way. Analogue signals from the sensors were supplied to the EIS where they underwent some signal conditioning and were digitised. The average of 8 samples was taken and passed through a software filter which provided a simple exponential lag. The filter output was subjected to a hysteresis level in order to improve the display stability. This hysteresis output was converted back to an analogue signal and fed to the FDAU then to the UFDR. The hysteresis output was also taken through further minor processing before being used to drive the counter display. It was converted to binary coded decimal (BCD) and stored in random access memory (RAM) in the required format for the counter display. The RAM contents were transferred to the display board under interrupt control.

The pointer display was also derived from signals taken from the filter output which were subject to a different hysteresis level before being scaled for the pointer, stored in RAM, and fed to the display under interrupt control. A simplified block diagram of the signal path is shown in Appendix 4, fig 1.

The vibration signals to the UFDR came directly from the AVM. All four vibration levels (LP compressor, LP turbine, HP compressor and HP turbine) were taken from the AVM and fed to the FDAU. They were then recorded at a sampling rate of once every 64 seconds. The route to the secondary EIS vibration displays was different in that the AVM sampled only the two compressor levels for each engine, it then detected the higher of these two levels and output only that signal to the EIS.

1.11.2 FDR data analysis

Appendix 4, fig 3 shows a plot of the engine parameters from 20.04 hrs as the aircraft was passing 26,000 ft at 300 kts calibrated airspeed (CAS) on the climb, until the final impact. The initial problem with the No 1 engine occurred at 28,300 ft, 295 kts CAS. The No 2 engine was throttled back as the aircraft began a descent from 30,000 ft and was then shut down at 20.07 hrs, 2 minutes and 7 seconds after the start of the first fluctuations of N1 on the No 1 engine. Power was reduced on the No 1 engine, and during the descent this engine was at flight idle for a period of 10 minutes. The power on the No 1 engine was increased at 20.20 hrs, at an altitude of 3000 ft, as the aircraft approached EMA.

Appendix 4, fig 4 shows the engine vibration parameters for the same period. These are recorded once every 64 seconds, but it can be seen that although the initial N1 fluctuations on No 1 engine lasted only some 22 seconds, the N1 compressor vibration levels on this engine remained at maximum for about 3 minutes. They decreased significantly once the No 1 engine was brought back to flight idle for the descent. Because of the low sampling rate for the vibration levels, it was not possible to determine exactly when the high vibration levels started. (see paragraph 1.16.3)

The maximum value which could be recorded by the FDR for vibration levels was 5 units. The values recorded for the N1 turbine and compressor levels on the No 1 engine corresponded to this maximum value after the initial engine vibration problem, and returned to this level some 4 minutes before impact as power was increased during the final approach. The actual level of vibration could have been much higher.

The No 1 engine N2 compressor and turbine vibration levels also showed a slight increase as the initial problem occurred and again when the power was increased on the No 1 engine during the final approach, although the levels were lower than those associated with the N1 compressor and turbine. The vibration levels on No 2 engine were normal throughout, and fell to zero once this engine had been shut down. The vibration level displayed to the crew on the vibration gauge would have been the N1 compressor level.

Appendix 4, fig 5 shows a more detailed plot of the initial engine parameters during the 'first event'. It shows that the No 1 engine fluctuations in N1, from the steady climb value of 99% to a minimum value of 74%, lasted for 22 seconds. There was also a slight rise and then fall in N2 from the steady climb value of 96%, to almost 97%, and back to around 93%. The EGT on No 1 engine also rose from the steady climb value of 780°C to a maximum of 900°C and then remained constant at around 830°C. No 1 engine fuel flow also dropped during this period. Just before the end of these fluctuations the autothrottle was disconnected and the power lever of the No 2 engine was moved to idle. At this time the No 1 engine stabilised at 96% N1, where it remained until it was throttled back for the descent. Throughout this time all indications on the No 2 engine remained steady and normal.

Appendix 4, fig 6 shows the final seconds of data from the FDR. The final sample of pressure altitude was 192 ft, based on 1013 mb. This corresponded to a height of 328 ft above mean sea level (amsl). The first impact of the aircraft with the ground occurred at 265 ft amsl. The last sample of radio altitude recorded was 30 ft above ground level (agl), and was recorded in word location 29, just before the recorder stopped at word 30.

The final second of data recorded on the FDR showed the aircraft in a nose-up pitch attitude of 15.1°, and a roll attitude of 4.8° to the right. The speed was 115 kts CAS. The final vane angle of attack recorded on the FDR was 26.4°, equivalent to 20.2° body angle of attack. The stick shaker was set to operate at body angles of attack above 16.7° and this angle was first exceeded 7 seconds before the FDR stopped. The recorded speed at this point was 124 kts CAS. This is shown in Appendix 4, fig 7 which gives the final flight path from a distance of 6 n.m. to the end of data. Stick shaker operation is not recorded on the FDR.

The actual speed at which the stick shaker operated would have depended on the rate of approach to the stall. In a steady stall entry, the stick shaker angle would correspond to a speed of 116.7 kts equivalent airspeed (EAS). The final speed on the FDR of 115 kts CAS was equivalent to 115 kts EAS for the prevailing flight conditions. For the configuration before impact the 1g stall alpha body angle of attack was 20.4°, which would correspond to a speed of 114.4 kts EAS in a normal stall entry.

1.11.3 Cockpit voice recorder (CVR)

The aircraft was equipped with a Fairchild model A100 CVR which was mounted at the rear of the aft baggage hold, on the right side. It was a slightly unusual installation in that it used a Sundstrand microphone monitor. This monitor contained the cockpit area microphone and was mounted in the overhead instrument panel on the flight deck.

The Fairchild CVR was of the usual 30 minute duration, endless loop type. It recorded on 4 tracks, the allocations of which were as follows:-

TRACK 1 - Commander's 'live' microphone (mic) and headset signals
TRACK 2 - Flight deck area mic.
TRACK 3 - Cabin address
TRACK 4 - Co-pilot's 'live' mic. and headset signals

The recorder was recovered from the aircraft on site. It was undamaged and a satisfactory replay was obtained using the AAIB's replay equipment. The audio quality of the CVR was good and a full transcript was produced for the period from the later stages of the climb until the end of recording.

1.11.4 CVR transcript significant events

From the CVR it was apparent that the first indication of any problem with the aircraft was as it approached its cleared flight level when, for a brief period, sounds of 'vibration' or 'rattling' could be heard on the flight deck. There was an exclamation and the first officer commented that they had 'GOT A FIRE'. The autopilot disconnect audio warning was then heard, and the first officer stated 'ITS A FIRE COMING THROUGH'. The commander then asked 'WHICH ONE IS IT?', to which the first officer replied, 'ITS THE LE..ITS THE RIGHT ONE'. The commander then said 'OKAY, THROTTLE IT BACK.'

London ATC was then called by the first officer, advising them of an emergency, after which the commander asked for the engine to be shut down. The first officer began to read the checklist for 'Engine Failure and Shutdown' but was interrupted by ATC calls and the commander's own calls to the operating company during which the decision was made to divert to East Midlands. Approximately 2 minutes after the initial 'vibration' the final command was given to shut down the engine. The first officer then recommenced the checklist and 2 minutes 7 seconds after the initial engine problem he moved the start lever of the No 2 engine to 'OFF'. He then started the APU. Throughout this period no fire audio warning was heard.

The aircraft then started the descent to East Midlands Airport and the commander made his first announcement to the passengers during which he mentioned that they had had a problem with their right hand engine which had produced some smoke in the cabin. The flight crew were then fully occupied with the relevant checklists, calls to the operating company and ATC, who were routeing them into East Midlands, and reprogramming the flight management system (FMS) for an East Midlands diversion, with which they had some difficulty. During this period they also briefly discussed the symptoms that had occurred initially and the commander mentioned 'RAPID VIBRATIONS IN THE AEROPLANE - SMOKE'.

The flight proceeded until the aircraft was on final approach with the landing checklist completed. Just after they had confirmed with East Midlands ATC that the right engine had been shut down, there was a crackling noise on the CVR, possibly due to electrical interference. This occurred 54 seconds before the first ground impact. Leading up to this event there were significant changes in the frequency content of the background noise on the CVR area microphone, which are discussed in paragraph 1.11.5. These changes would probably not have been audible to the crew.

Immediately following this, a transmission was made to the tower indicating that the crew was having trouble with the second engine as well and the commander asked the first officer to 'TRY LIGHTING THE OTHER ONE UP - THERE'S NOTHING ELSE YOU CAN DO'.

36 seconds before impact the (No 1 engine) fire bell sounded. The first officer asked the commander if he should shut this engine down. The commander replied in the negative. The CVR recording then indicated their intention to 'stretch the glide', but at 29 seconds before impact the ground proximity warning system (GPWS) 'glideslope' warning commenced and continued with increasing repetition rate, indicating that the aircraft was steadily diverging below the glidepath. The commander twice said 'TRY OPENING THE OTHER ONE UP' and each time the first officer said 'SHE'S NOT GOING'. At 10 seconds before the impact the commander made an announcement to the passengers to 'PREPARE FOR CRASH LANDING' (repeated). The stick shaker was then heard operating, followed by the sounds of impact.

Relevant comments from the CVR transcript are shown in relation to the FDR information in the Appendix 4, figs 2, 5 & 7.

1.11.5 CVR frequency analysis

An analysis was carried out of the frequency content of the background noise from the area microphone. This was done to identify any changes in the frequency signatures that might have indicated an engine problem before the crew became aware of it.

This analysis was carried out using a Hewlett-Packard model 13561A dynamic signal analyser. The first significant change in the frequency signature occurred just after the onset of the initial vibration and smoke, when harmonics of the frequency associated with 'once per revolution' of an LP shaft became detectable. This was indicative of either vibration of the shaft, damage to a limited number of blades on the shaft, or a combination of the two. The amplitude of the dominant frequencies changed with the variations in power taking place, but became particularly high just before the No 1 engine was throttled back to flight idle for the descent. Thereafter, and up until power was increased for the final approach, the frequencies associated with the LP shaft were not detectable. Appendix 4, fig 8 shows comparisons of the signatures of frequencies up to 625 Hz for the start of the CVR tape (aircraft level at 6,000 ft); the climb; and significant points immediately after the first event.

As the No 1 engine power was increased on the final approach, the frequencies associated with the LP shaft once again became detectable, and varied with the changes in engine speed. They became increasingly audible during replay of the area microphone track in the AAIB audio laboratory until the point at which the 'crackle' was heard, when they were no longer detectable. This was indicative of this second event also having been associated with the LP shaft (the FDR data showed a sudden drop in the No 1 engine N1 coincident with this point). These changes in audio content were probably not detectable by the crew within the flight deck environment. Appendix 4, fig 9 shows a comparison between the signatures just before, and just after, this second event.

* 1.12 Wreckage and impact information

1.13 Medical and pathological information[2]

39 passengers died at the scene of the accident, 8 more died in hospital at times up to 22 days later. 79 passengers and crew survived.

The acute medical care of the 87 passengers and crew removed from the site alive was undertaken by hospitals in Nottingham, Leicester, Derby and Mansfield. The response of the Ambulance Services and the Health Authority to this incident has been documented by the Trent Regional Health Authority[1]. The pathological investigation was conducted by a team of civilian pathologists and by a multidisciplinary team from the Royal Air Force Institute of Pathology and Tropical Medicine, including the RAF Dental Branch.

1.13.1 *Injuries*

All passengers and crew suffered varying degrees of injury during the aircraft impact. Information on the severity of the injuries sustained by the passengers and crew is displayed anonymously in Appendix 5, figs 1 & 2. The impact damage sustained by the aircraft is shown to assist in the understanding of the mechanism and degree of injury.

Appendix 5, fig 1 shows the distribution of ultimate survivors and fatalities from the accident. Appendix 5, fig 2 shows the Injury Severity Score (ISS) that was coded for the injuries that each passenger and crew member sustained[2]. The ISS is a scheme for denoting the magnitude of the injury suffered in a manner that permits an assessment of outcome. The American Association for Automotive Medicine Abbreviated Injury Score[3] (1985 revision) was used. The injury score

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**ICAO Note.*— Section 1.12 was not reproduced.

[2] All superscripts in this section denote references listed in Appendix 5.7

was calculated using the system of Baker et al[3] as the sum of the squares of the three highest regional Abbreviated Injury Scores. It can be seen that the most severe injuries occurred in rows 6-8 in the region of the forward fuselage break, with serious injuries occurring in the whole of the area forward of the wing where the floor structure failed. Further serious and fatal injuries occurred in the region of the failure of the rear fuselage and floor, and in the area where the tail structure had swung over, and into, the rear fuselage. The least injuries occurred in the rear of the aircraft. Appendix 5, fig 3 shows the distribution of the survivors and fatalities in the aircraft, coded according to whether their ISS was above or below 16; this figure represents the ISS at which an approximately 10% fatality rate has been reported[3].

1.13.2 *Types of injury*

Head injury

All but one of the 39 fatalities at the scene of the accident sustained head injuries of varying severity. 43 non-survivors had facial injuries. 74 of the 83 patients removed to hospital had suffered head or facial injury. 31 cases of facial injury required treatment. 17 patients showed clinical evidence of a strike to the head from behind. 43 of the patients presenting at hospital had suffered an episode of impairment of consciousness. 5 of the 83 patients removed to hospital had suffered severe head injuries.

Neck injury

21 non-survivors and 6 survivors sustained injuries to neck structure.

Upper limb and shoulder injury

19 fatalities and 28 survivors sustained fractures and dislocations of the upper limbs and shoulders.

Chest injury

Some degree of generally major chest injury was found in all but one of the fatalities. 18 of the 79 survivors also suffered major chest trauma.

Abdominal injury

36 fatalities suffered abdominal trauma compared to only 2 of the survivors who suffered a major abdominal injury.

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[3] Shingling: The overlapping of root platforms or mid span shrouds as a result of peripheral blade lean.

Lower limbs and pelvis

22 survivors and 13 non-survivors sustained pelvic injuries. A considerable number of lower limb injuries also occurred. 22 survivors and 13 non-survivors sustained fractured femurs; 18 survivors and 5 non-survivors sustained knee injuries; 31 survivors and 38 non-survivors sustained lower leg fractures; 26 survivors and 24 non-survivors sustained fractures/dislocations of the ankle; and 22 survivors and 6 non-survivors sustained fractures of the bones of the feet. Many of those affected suffered fractures of more than one area. Only 18 surviving passengers and 6 non-surviving passengers had no injury to the lower limbs and pelvis.

1.14 Fire

There were two separate areas on the No 1 engine which had been affected by fire and these were the only areas where there was evidence of fire on the aircraft. The most seriously affected zone was on the fan case within the forward engine cowling, and the less serious zone was on the rear edge of the reverser duct, on the outboard side.

Ground witness reports indicated that immediately after the ground impact of the aircraft the only fire visible was relatively localised and centred around the forward end of the No 1 engine, but that after a short time the fire suddenly grew in intensity. Upon the arrival of the airport fire service, the fire was quickly extinguished using a combination of aqueous film forming foam (AFFF) and fluoroprotein foams.

1.15 Survival aspects

1.15.1 *On-board emergency preparations and impact effects*

Following the initial engine problem the cabin attendants collected the in-flight meals, which had not long been served. After the diversion to the East Midlands Airport was announced, the attendants checked the passengers' seat belts and stowed all the loose carry-on luggage in the overhead bins. Approximately 10 seconds prior to the first impact the commander warned the passengers to prepare for a crash landing.

Some, but not all, of the passengers adopted a crash position prior to the aircraft striking the ground. One young child was secured on his mother's knee using a supplementary lap belt (seat 3F). Both the mother and child were injured during the impact, the mother sustaining a greater degree of injury, as evidenced by the ISS score, than other passengers sitting around her.

Several of the passengers described heavy vibration immediately prior to the impact and one passenger, in the rear of the aircraft, described the vibration as being severe enough to open the overhead lockers and cause them to spill contents. Passengers in the rear of the aircraft described two distinct impacts; those in the front appeared only to have been aware of the final impact.

During the impact the fuselage broke into 3 main sections, with 4 distinct areas of damage (paragraphs 1.12.2.6 & 7): the area forward of the wing (rows 1-9), where the floor structure was completely disrupted and all the seats became detached, the centre section (rows 10-17), where the majority of the seats remained attached to the floor; and the area behind the wing (rows 18-23L/24R), where the floor failed and the fuselage was disrupted, both circumferentially and from above, by the overturning tail section, in which seat rows 24L/25R-27 remained attached.

In the forward area where the seats became detached, passengers were trapped by the seats moving forward, compressing their occupants. A number of passengers in this area sustained severe crushing injuries.

Following the impact the majority of the passengers were trapped due to injury, seat failure or debris from overhead. Only 14 of the passengers were able to make a significant contribution to effecting their own escape.

Both pilots were trapped, as was one of the two stewardesses in the front flight attendant seat. One stewardess, seated on the rear flight attendant double seat, reported that she had been injured and trapped by a food service cart. The other occupant of this seat was released by the steward, who had been seated on the single seat adjacent to the right rear door.

1.15.2 Rescue operations

ATC at East Midlands Airport declared a full emergency at 2008 hrs, alerting the Airport Fire Service (AFS) and the civil emergency services. Vehicles of the AFS deployed immediately to two holding points alongside the mid-section of the runway. Whilst in this position, the AFS attempted to speak to the aircraft on their emergency frequency but were unable to make contact. Vehicles from the Leicestershire Fire Service moved to a pre-arranged rendezvous point at the airport, arriving at 2023 hrs. The AFS crews in the vehicles near the runway saw the aircraft descend below the motorway embankment and moved immediately to the crash site, two vehicles proceeding via the runway and the eastern crash gate and the other via the airport main entrance. The AFS identified and broadcast the exact location of the aircraft at 2029 hrs and were in action extinguishing the fire at 2033 hrs. The vehicles of the Leicestershire Fire Service, travelling via the main entrance, reached the motorway intersection 200 metres north of the site at 2032 hrs and joined the AFS at the scene of the crash shortly afterwards. Immediately afterwards additional vehicles from the Nottinghamshire and Derbyshire Fire Services arrived at the site to assist in rescue work.

At 2012 hrs the police notified the emergency to the Leicestershire Ambulance Service, who immediately despatched ambulances to the airport rendezvous point. These vehicles followed the fire vehicles to the scene. At 2020 hrs the Leicestershire Ambulance Service requested support from the Derbyshire and Nottinghamshire services, whose vehicles were moving towards the airport before the crash occurred. In addition, when they heard news of the accident, the Staffordshire Ambulance Service volunteered assistance. During the rescue operation, the 3 adjacent counties provided 69 ambulances, and 5 were provided by the Staffordshire service. Royal Air Force helicopters and Mountain Rescue Teams also moved to the site when alerted by the Rescue Coordination Centre (RCC) (see paragraph 1.17.5.2). Further assistance was provided by the Army and the Derbyshire Miners' Rescue Team. The Salvation Army provided a mobile canteen service for the rescue workers.

After extinguishing the fire, the fire services laid a blanket of foam as fire protection against leaking fuel, and this blanket was constantly refreshed as the rescue operation continued. Fire and ambulance services, assisted initially by passing motorists, began to recover the survivors from the aircraft and move them to hospital with the minimum of delay. RAF helicopters were used to move some of the more seriously injured passengers to hospital.

The evacuation of the passengers was prolonged. The last passenger was not extricated from the aircraft until 0420 hrs. The survivors were taken to the University Hospital, Queen's Medical Centre, Nottingham, the Derbyshire Royal Infirmary, the Leicestershire Royal Infirmary and the Mansfield and District General Hospital.

* 1.16 Tests and research

* 1.17 Additional information

1.18 New investigation techniques

The use of the KRASH computer program (paragraph 1.16.4) for the analysis of the aircraft impact sequence was the first time that this type of computer-based dynamics modelling had been used as part of an aircraft accident investigation.

**ICAO Note.*— Sections 1.16 and 1.17 were not reproduced.

Previous uses had included the prediction of crash dynamics in controlled impact demonstrations. The simulation was conducted within a time-scale compatible with the accident investigation process and made a distinct contribution to the crashworthiness and survivability aspects of this investigation.

The occupant simulation study (paragraph 1.16.5) was computer-based and was undertaken by H W Structures Ltd, using the crash victim simulation program MADYMO. Although this type of occupant response simulation has been in use for some time in automotive safety engineering, this appears to have been its first use within the context of the investigation of a transport aircraft accident.

2. ANALYSIS

2.1 Crew actions

2.1.1 The reaction of the flight crew to the engine problem

2.1.1.1 Fault diagnosis

After an uneventful take-off and climb the crew suddenly heard an unusual noise, accompanied by vibration, as the aircraft passed through FL 283. The noise was heard in the cabin as a series of thuds and the FDR indicated that it was directly associated with the stalling of the fan and/or the LP compressor with attendant surging of the No 1 engine. In addition to the noise and vibration, the lateral and longitudinal accelerations recorded on the FDR were consistent with the reported lower frequency shuddering that was sufficiently marked to shake the walls of the forward galley. Very soon after the onset of these symptoms there was a smell of fire and possibly some visible smoke in the cockpit. This combination was interpreted by the pilots as evidence of a serious engine malfunction, with an associated fire, and appears to have driven them to act very quickly to contain this perceived condition.

Neither pilot appears to have assimilated from the engine instruments any positive indication of malfunction, but subsequent tests showed the engine instrument system to have been serviceable and there was no evidence to indicate that it did not display the large engine parameter variations that occurred when the compressor surged. The FDR showed four distinct excursions in N1 on the No 1 engine, with a 6 second period of relative stability between the second and the third.

Throughout the period of compressor surging, the No 2 engine showed no parameter variations but because the first officer was unable to recall what he saw on the instruments, it has not been possible to determine why he made the mistake of believing that the fault lay with the No 2 engine. When asked which engine was at fault he half-formed the word 'left' before saying 'right'. His hesitation may have arisen from genuine difficulty in interpreting the readings on the engine instruments, or it may have been that he observed the instruments only during the 6 second period of relative stability between the second and third surges. However, any uncertainty that he may initially have experienced appears to have been quickly resolved because, when the commander ordered him to 'THROTTLE IT BACK', without specifying which engine was to be throttled back, the first officer closed the No 2 throttle.

The commander said that he gained from the engine instruments no clear indication of where the trouble lay. He had, however, disengaged the autopilot 8 seconds after the first compressor surge and most of his attention thereafter would probably have been on the handling of the aircraft and the flight instruments. The fact that when the aircraft rolled to the left he made no corrective movements with the flying controls appeared to indicate that he did not detect from the behaviour of the aircraft any loss of thrust from the No 1 engine. After the accident, he stated that he had judged the No 2 engine to be at fault from his knowledge of the aircraft air conditioning system. His reasoning was that he thought the smoke and fumes were coming forward from the passenger cabin; the air for the cabin came mostly from the No 2 engine; therefore the trouble lay in that engine. Whilst this reasoning might have applied fairly well to other aircraft he had flown, it was flawed in this case because some of the conditioning air for the passenger cabin of the Boeing 737-400 comes from the No 1 engine. In any case, his assessment was not supported by the evidence because the fumes had been perceived in the cockpit, and it was not for some time that he was able to confirm from the flight service manager that there had also been smoke in the passenger cabin. It seems unlikely that in the short time before he took action his thoughts about the air conditioning system could have had much influence on his decision. It is considered to be more likely that, believing the first officer had seen positive indications on the engine instruments, he provisionally accepted the first officer's assessment.

The speed with which the pilots acted was contrary to both their training and the instructions in the Operations Manual. If they had taken more time to study the engine instruments it should have been apparent that the No 2 engine indications were normal and that the No 1 engine was behaving erratically. The commander himself might have had a better chance to observe these abnormal indications if he had not disengaged the autopilot, but this action by itself should not have prevented him from taking whatever time was necessary to assimilate the readings on all the engine instruments. In the event, both pilots reacted to the emergency before they had any positive evidence of which engine was operating abnormally. Their incorrect diagnosis of the problem must, therefore, be attributed to their too rapid reaction and not to any failure of the engine instrument system to display the correct indications.

Therefore, in view of the possibility of future occurrences of severe engine out-of-balance conditions and concern regarding the possible reactions of flight crews involved, it was recommended that the CAA should take action to advise pilots of Boeing 737-300/400 aircraft, and of other types with engines which have similar characteristics, that where instances of engine-induced high vibration occur, they may be accompanied by associated smoke and /or smells of burning entering the flight deck and/or cabin through the air-conditioning system, due merely to blade tip contact between fan/compressor rotating assemblies and the associated abradable seals. (Made 23 February 1989).

2.1.1.2 The recovery of the No 1 engine

There then occurred an event that led both pilots into the fatal misconception that the action they had taken in haste had in fact been the correct action. As soon as the No 2 engine throttle was retarded, the symptoms they described as 'vibration' appeared to cease. The No 1 engine compressor surges and the associated noise and shuddering certainly ceased at this time, most probably because the autothrottle was disconnected (see paragraph 2.2.2.2), but the FDR showed that the high vibration level did not. However, although this vibration continued to show on the FDR and was felt by many of the passengers, it appears to have been no longer perceived by the pilots, and the smell of burning seems not to have intensified. Thus, having failed to note the continuing maximum reading on the No 1 engine vibration indicator or the fluctuating fuel flow and being apparently unaware of the continuing vibration, both pilots were convinced that closing the No 2 throttle had stopped not only the noise and the shuddering but also the vibration, as was shown by the commander's comment some 50 seconds later when he said 'SEEMS TO BE RUNNING ALRIGHT NOW'.

From subsequent tests it is apparent that the No 1 engine vibration indicator was at the top of its scale within 2 seconds of the onset of vibration and remained there for about 3 minutes, until after that engine was throttled back for the descent. Yet it appears that the reading on this indicator was not noticed by either pilot, and this indicates a weakness in training philosophy. The commander seems to have been aware of the less than satisfactory performance of the earlier types of vibration monitor, probably from his past experience on the McDonnell Douglas DC9. His subsequent training by Boeing on the 737 did not draw his attention to the much improved performance of the newer AVM system, and he had not practised an emergency in which the AVM indications were used as a visual cue to assist him in fault diagnosis. Similarly the first officer, who had no previous experience on turbojet or turbofan powered aircraft, had not had his attention drawn to the AVM indicators in this context during his training. Both pilots, however, should have been aware of the Operations Manual Bulletin issued by Boeing in March 1988, which introduced the procedure to be followed in the event of high engine vibration. This bulletin implicitly drew attention to the vibration indicators. It was therefore recommended that the CAA should review the current attitude of pilots to the engine vibration indicators on Boeing 737-300/400 aircraft, and other applicable types with turbofan engines, with a view towards providing flight crews with an indication of the pertinence of such vibration instruments when engine malfunctions or failures occur (Made 23 February 1989). In addition, it is further recommended that the CAA should require that pilot training associated with aircraft which are equipped with modern vibration systems, and particularly those aircraft which are fitted with high by-pass turbofan engines [4], should include specific instruction on the potential value of engine vibration indicators in assisting the identification of an engine which has suffered a failure associated with its rotating assemblies (Made 30 March 1990).

2.1.1.3 *The engine instrument system*

The failure to detect, or at least to identify correctly, disparities in the readings of the engine instruments is perhaps most important with regard to the vibration indicators. Unlike the transient fluctuations that would have appeared on the primary engine instruments, the reading on the No 1 engine vibration indicator rose to maximum and remained there for about 3 minutes. On the EIS, however, not only is the pointer of this vibration indicator much less conspicuous than a mechanical pointer (Appendix 2, figs 1 & 2) but, when at maximum deflection, it may be rendered even less conspicuous by the close proximity of the No 1 engine oil quantity digital display, which is the same colour as the pointer and is the dominant symbology in that region of the display (Appendix 2, fig 3). In view of the limited attention both pilots appear to have given to the vibration indicators, it is a matter for conjecture whether or not they would have failed to notice such a maximum reading on the mechanical pointer of a hybrid display, clearly separate from any other distracting indication, but there can be little doubt that it would have been easier to see.

The informal survey of pilot opinion of the EIS (paragraph 1.17.3) showed that 64% preferred engine instruments with full length mechanical pointers. This finding was almost certainly influenced by lack of familiarity since the survey was

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[4] Excluding those aircraft fitted with a computerised engine warning system which includes engine vibration as an alerting parameter.

conducted when the EIS was relatively new in service, and it is not surprising that at that time most pilots should have expressed a preference for the older type of display, with which they were familiar. The result of the survey was also influenced by the replies of the BMA pilots, which were more critical of the EIS than those of other airlines. Also, because of a natural resistance to change, the fitness of new equipment for its purpose may not be judged on pilot preference alone, although this must be an important factor. With these reservations, the least favourable interpretation of the results was that the EIS displayed engine parameters clearly, but its ability to attract attention to rapidly changing readings was less satisfactory. The latter aspect, however, was less important in the case of this accident because the crew were alerted to abnormal operation by other signs and had time, or should have taken time, to study the engine instrument readings.

One finding of the pilot survey, that the LED pointers of the EIS are less conspicuous than the mechanical pointers on the hybrid displays, is however a cause for concern. In this respect, whilst the introduction of the EIS may represent progress in terms of improved reliability and maintainability, it may be a retrograde step in terms of presentation of information. Moreover, although it was type-certified as fit for its purpose by both the FAA and the CAA during October 1988, it appears to have been introduced without any thorough evaluation of its efficiency in imparting information to line pilots. Now that the system has been in use for some time and EIS-equipped flight simulators are available, the reduced conspicuity of the pointers may assume less importance and it may be too late for a new evaluation of the system to be worthwhile. Nevertheless, this change in presentation indicates how important it is for all new developments in aircraft indicating systems to be subjected to comprehensive evaluation of their effect on line pilot performance before being introduced to service. It is therefore recommended that the regulatory requirements concerning the certification of new instrument presentations should be amended to include a standardized method of assessing the effectiveness of such displays in transmitting the associated information to flight crew, under normal and abnormal parameter conditions. In addition, line pilots should be used in such evaluations (Made 30 March 1990).

The layout and methods of displaying information on engine instruments are considered in Appendix 2.7, which concludes that although the EIS provides accurate and reliable information to the crew, the overall layout of the displays and the detailed implications of small LED pointers, rather than larger mechanical ones, and of edge-lit rather than reflective symbology, require further consideration. Neither pilot noticed the maximum reading on the No 1 engine vibration indicator and at least one of them gained the impression from the engine instruments, or from some other cue, that the No 2 rather than the No 1 engine was failing. If they gained this impression from the engine instruments then there is a possibility that the methods of displaying information on these instruments may have contributed to the error.

The error would probably not have been made if the vibration indicators had included a visual warning of which engine was affected by excessive vibration. It may be seen from the preamble to the FAA requirement for a vibration monitoring system (paragraph 1.17.4) that it was intended to provide the flight crew with a vibration warning, and later aircraft powered by certain high-bypass turbofan engines, such as Boeing 757 aircraft and the Airbus series, do include high engine vibration in their crew alerting systems. It is therefore recommended that the CAA should require that the engine instrument system on the Boeing 737-400 aircraft type, and other applicable public transport aircraft, be modified to include an attention-getting facility to draw attention to each vibration indicator when it indicates maximum vibration (Made 30 March 1990).

2.1.1.4 *The shut-down of the No 2 engine*

Although the initial misidentification of the damaged engine may be seen as the start of the accident sequence, the commander's decision to throttle back the No 2 engine did not, by itself, lead directly to the accident. In fact this decision would have been entirely appropriate in the absence of any positive indication on the engine instruments; he would then have reduced power on each engine in turn in order to identify the one that was causing the vibration. It is likely that, if the No 1 engine had not ceased to surge at the same time that the No 2 throttle was closed, an effect considered to be connected with the disconnection of the autothrottle (paragraph 2.2.2.2), the accident would not have occurred.

It is also likely that, if the No 2 engine had not been shut down, the accident would not have happened, and some explanation must be sought for the commander's decision to shut it down. It is now known that the engine was operating normally but, because the decision to shut it down was made after its throttle had been closed, having failed to recognise its normal operating parameters before closing the throttle, the crew could no longer confirm its normal operation by comparison with the No 1 engine instruments. There is, however, no evidence from the CVR that the crew consulted the engine instruments or attempted any other analysis of their situation before shutting down the No 2 engine. Indeed, it appears that they were so sure that they had contained the situation that the commander engaged in lengthy communications with BMA Operations just after the No 2 throttle had been closed.

It may be indicative of what was in their minds that, when the first officer notified the emergency to London Airways, he said '...AT THE MOMENT IT'S

LOOKING LIKE AN ENGINE FIRE....', and it may be that the commander's further action was taken in the belief that the engine was on fire. If this was the case, then he should not have accepted the first officer's selection of the 'Engine Failure and Shutdown' checklist, when the 'Engine Fire, Severe Damage or Separation' checklist would have been more appropriate. Once the No 2 engine had been shut down, it would appear that the apparent absence of any manifestation of abnormality other than the No 1 engine vibration indication, which they did not notice, persuaded both pilots that, in the commander's own words, '.... *the emergency had been successfully concluded and the left engine* was operating normally.' Moreover, as the commander also said later, the clearance from the flight deck of the smell of fire powerfully reinforced their conviction that they had taken the correct action.

In the aircraft 'non-normal' checklist severe vibration does not necessitate an engine shut-down, provided it is not accompanied by abnormal engine indications, nor does the presence of smoke or fumes in the cockpit. The crew, therefore, did not comply with the checklist in shutting down the engine since they did not see any abnormal engine indications. Nor did they follow the more general instructions in the Operations Manual or their training, both of which required them to evaluate all the evidence available before taking this action. However, the Operations Manual contained no guidance on the action to be taken *in the event that vibration and smoke/fumes occurred together.* Because severe fan shaft vibration can cause damage to the fan and/or the LP compressor abradable seals, and fumes can enter the aircraft from these sources, it would have been prudent for the aircraft manufacturer to have included an appropriate warning and a suitable procedure for such a contingency in the aircraft Flight Manual. It was therefore recommended that the CAA should request the Boeing Commercial Airplane Company to produce amendments to the existing aircraft Flight Manual to indicate what actions should be taken when engine-induced high vibration occurs, accompanied by smoke and/or the smell of burning entering the flight deck and/or cabin (Made 23 February 1989).

2.1.1.5 Subsequent actions of the operating crew.

Having shut down the No 2 engine, the commander decided to land at the nearest suitable airfield. Although it is possible that he was influenced by the fact that East Midlands Airport (EMA) was his company's main operating base, it is more likely that he was influenced by the urgency which he felt when he first smelt 'fire'. He initiated a flight pattern that would enable him to land the aircraft with the minimum delay, but which left him little time to reconsider the nature of the *emergency or the actions* that had been taken. Whilst the decision to land without delay was correct, the shortness of the flight time between Event 1 and the approach to land at EMA may have influenced the outcome of the emergency.

From the start of the descent the cockpit workload was high as the pilots received and acknowledged ATC directions, notified their situation to the operating company, broadcast to the passengers on the cabin address system and completed the descent and approach checklists for a single-engined landing. Some time was lost as the first officer attempted unsuccessfully to programme the flight management system (FMS) to produce the correct flight instrument display for landing at EMA. Such reprogramming of the FMS for landing at a hitherto unspecified diversion airfield is unusual and rarely if ever practised. From the CVR it may be inferred that he possibly attempted to enter EMA as the next en route point without first selecting the route page and entering it as an arrival airfield. It is therefore recommended that the CAA should ensure that flight crew currency training in simulators includes practice reprogramming of flight management systems, or any other such systems which control key approach and landing display format, during unplanned diversions so that they remain practised in the expeditious use of such systems (Made 30 March 1990).

More time was spent when the commander accepted a request from EMA to make a call to the fire vehicles. Nevertheless, it must have seemed to the commander that his plan allowed all necessary tasks to be completed in time, for he made no attempt to slow down the rate of activity or to re-engage the autopilot to reduce his own workload, and he did not ask ATC for a quiet radio frequency. When, some 7 minutes after the engine was shut-down, the commander began to review what had occurred, the reading on the No 1 engine vibration indicator had reduced and there was no other indication on the engine instruments of the damage to that engine. When his review of events was interrupted by an ATC transmission, he did not resume it, and this seems to indicate that he remained confident of the safety of the aircraft. There can be little doubt, however, that the high workload in the cockpit contributed to the failure of the crew to notice the abnormally high reading on the No 1 engine vibration indicator that was evident for nearly four minutes after the initial vibration. It is therefore recommended that the CAA should review the current guidance to air traffic controllers on the subject of offering a discrete RT frequency to the commander of a public transport aircraft in an emergency situation, with a view towards assessing the merits of positively offering this important option (Made 30 March 1990).

Even at that stage of the approach to land when there was still time to restart the No 2 engine, the commander obtained a required increase in power from the No 1 engine, which must again have confirmed to him that his previous actions had been correct. The engine, however, again produced high vibration, which elicited no comment by either pilot and appears not to have been perceived against the background of cockpit activity at the time. 4 minutes later the No 1 engine lost power and the accident became inevitable. Although the commander instructed the first officer to restart the No 2 engine some 50 seconds before the crash, and the CVR recorded that the first officer attempted to comply, the No 2 engine fan shaft showed no significant rotation at impact.

At this time flight conditions were outside the envelope for a 'windmill' start. Starter assistance would have been needed to rotate the engine, requiring the No 2 engine start switch to be selected to the 'GRD' position. Because this switch would have moved automatically to 'OFF' as soon as electrical power was lost, there was no evidence to show whether or not a starter assisted start was attempted.

However, the normal starter assist procedure would perhaps not have been effective for there would probably have been insufficient bleed air pressure from the failing No 1 engine to rotate the No 2 engine, and without rotation there would have been no fuel flow to the engine. It is likely, therefore, that the only procedure that would have restarted the engine was that appropriate to a restart from a condition of double engine failure, which would have required both air conditioning packs to have been switched off and pressure air from the APU to have been connected to the bleed air manifold. The checklist in the Quick Reference Handbook gave a procedure suitable only for the restart of the No 1 engine and an attempt to start the No 2 would have required improvisation. This checklist has since been amended to cover the restart of either engine. After the accident the positions of the switches on the bleed air control panel showed that no double engine failure restart drill had been attempted. The first officer, however, had comparatively little experience of the aircraft and could not have been expected to recognize the need for, improvise and accomplish an unlisted procedure in the time between the final loss of thrust on the No 1 engine and the impact with the ground. Even if he had devised and followed a suitable procedure, it is doubtful if the engine could have been started and brought up to idle speed in the short time available.

2.1.2 *Crew cooperation*

2.1.2.1 *Flight crew coordination*

Among the important factors that affect the ways in which individual crew members relate to one another are their personalities, relative ranks, roles (*ie* handling, non-handling) and relative levels of competence. The commander, although he had no management or training responsibilities, had been a captain with the operating company for 14 years, whereas the first officer had flown jet transport aircraft for only 6 months. Nevertheless, this wide difference in rank and their limited previous association appear not to have influenced coordination adversely. The CVR did not suggest any undue deference from the first officer to the commander, and the atmosphere appeared relaxed in the early part of the flight with both pilots addressing each other by their first names.

Although the first officer was the handling pilot when the emergency occurred, the commander then disengaged the autopilot and, although no words were said, it was apparent to the first officer that the commander had taken control of the aircraft. This change in handling may have had an effect on the first officer's ability to interpret the engine instrumentation. Since he was likely to have been more concerned with handling the aircraft than with monitoring these instruments during the early part of the flight, he was not, perhaps, as acutely associated with interpreting them as he would have been as the non-handling pilot, and this rapid change of perceptual 'set' could have contributed to his identification of the wrong engine.

The relative and absolute levels of competence of the crew members are difficult to gauge. Both pilots had met company requirements during conversion training and subsequent base and line checks, and their training records reflect no difficulty in comprehension, or lack of competence. There is, therefore, no suggestion that any large ability mismatch on the flight deck affected coordination. Indeed, the CVR suggests that the pilots worked together as a team throughout the flight, and that the decisions made on the flight deck were all accepted jointly.

2.1.2.2 *Coordination between the flight deck and the cabin*

It was extremely unfortunate that the information evident to many of the passengers of fire associated with the left engine did not find its way to the flight deck even though, when the commander made his cabin address broadcast, he stated that he had shut down the 'right' engine. The factor of the role commonly adopted by passengers probably influenced this lack of communication. Lay passengers generally accept that the pilot is provided with full information on the state of the aircraft and they will regard it as unlikely that they have much to contribute to his knowledge. Even those passengers who noticed the commander's reference to the right engine may well have assumed that the commander had made a slip of the tongue, or that the problems they had seen with the left engine were in some way consequential to an important problem with the right engine that the commander had dealt with. It cannot therefore be regarded as surprising that information from the passengers was not made available to the pilots.

The same information was available to the 3 cabin crew in the rear of the aircraft but they, like the passengers, would have had no reason to suppose that the evidence of malfunction they saw on the left engine was not equally apparent to the flight crew from the engine instruments. In addition, it would appear that there was not the same awareness of possible error, since these cabin crew members stated that they had not heard the commander's reference to the right engine. This may have been because the cabin crew, engaged on their own duties, were not aware of any more than the general sense of the broadcast. In addition, cabin crew are generally aware that any intrusion into the flight deck during busy phases of flight may be distracting, and this is particularly true if the flight crew are known to be dealing with an emergency. There can thus be at these times a firm division between flight deck and cabin, and it is notable in this context that in this accident the flight service manager made no initial attempt to approach the flight deck until he was called. However, it must be stated that had some initiative been taken by one or more of the cabin crew who had seen the distress of the left engine, this accident could have been prevented. It must be emphasised, nonetheless, that present patterns of airline training do not provide specifically for the exercise of coordination between cabin and flight crew in such circumstances.

2.1.3 The influence of stress

One aspect of flying that is extremely difficult to address in training is the stress presented by an emergency. Although all pilots are aware of the general requirement to avoid making hasty decisions in the air, it is much easier to advocate such a policy on the ground than it is to execute it in the air when presented with an unusual emergency. The response of any individual to a given emergency will be affected by three factors - the perceived severity of the problem, the personalities of the individuals concerned and the training they have received.

The noise and smell which suddenly alerted this crew to the emergency quickly led them to believe that they were experiencing a severe problem, and it may reasonably be assumed that this would have had a marked effect on their affective states. No formal assessment of the personalities of the pilots has been undertaken, but there was nothing in their records to suggest that they were likely to differ significantly from most other pilots in their response to stressful stimuli.

It is notable from many accidents that crews are more likely to remain calm during hazardous events if they understand the situation and have an appropriate drill to implement. In this accident the combination of initial symptoms was outside their experience and training, and there was no specific drill for such a combination. Thus the combination of severity and novelty must have acted to increase their arousal. Under such circumstances it is understandable that their first desire was to identify the problem. Although this is obviously a first requirement in order that action may be taken, uncertainty reduction also has considerable psychological importance in that it is much more comfortable and reassuring to be able to impose structure on a situation and deal with a known rather than an unknown problem. Two effects of increased arousal on the desire to reduce uncertainty may be contemplated. The first is unnecessary haste in making a decision about the nature of the problem and the second is failure to question that decision, once it has been made.

Although there is evidence in this accident that both these factors may have prevailed to some extent, there is no evidence that this crew was abnormally affected by stress, or that they responded to the situation in a uniquely unexpected manner. In particular it should be noted that the second of these effects - the reduction in likelihood that they might question the accuracy of their decision - would have been heavily influenced by the fact that the reduction in No 2 engine power had apparently stopped the shuddering. There is considerable research on the topic of 'causality' from which it is clear that in this situation it would have required an exceptional crew to question the association between their action and its apparently obvious, and highly desirable, consequence. The commander attempted, during a period of slightly lower workload, to review the events that had passed. It was unfortunate that further events intervened to curtail this review since it is possible that he may have realised, given more time, that there was a risk that they might have shut down the wrong engine.

A last factor which may have influenced this crew's behaviour, given the stressful nature of the events, is the flight simulator training which they would have experienced. In the simulator virtually all engine problems result in an engine shutdown. Since this crew would have been under both practical and psychological pressure to come up with a programme of action, it cannot be regarded as surprising that the actions they embarked upon were those that they had practised in the flight simulator.

2.1.4 *Flight crew training*

The performance of flight crew in emergency situations may be regarded as a product of their natural ability and their training. It is possible to identify three aspects of the circumstances of this accident where a different pattern of training could have favourably influenced the outcome. The ability of the pilots to extract information from the EIS must be questioned, and so must the apparent lack of coordination between the flight deck and the cabin crew. The most important issue, however, concerns the preparation of pilots generally to cope with unforeseen situations which are not covered in their emergency checklists.

2.1.4.1 *Training on the EIS*

When the operating company took delivery of their first EIS equipped aircraft, training on the EIS was included in a one day course on the differences between the Series 300 and Series 400 aircraft (paragraphs 1.5.1 and 1.5.2). No EIS equipped flight simulator was available at that stage and so the first few flights of pilots who were new to the EIS system were supervised under normal line checking procedures. The result of this pattern of training was that the first time that a pilot was likely to see abnormal indications on the EIS was in-flight in an aircraft with a failing engine. This could be regarded as undesirable on at least two counts. The first is that if the crew encountered any problem with display interpretation under normal line conditions, there would invariably be spare capacity in the system to enable them to spend a little extra time checking the readings on the display. In the circumstances of this emergency, they may not have perceived that such time was available, and were thus in a situation where they had to interpret novel readings (*ie* acquire a new skill) under the worst possible conditions. The second reason is that it is possible that new forms of engine instrumentation are, subjectively, more different from the old instrumentation when presenting abnormal readings than when presenting normal states, and that the slightly different techniques required to interrogate these instruments under abnormal conditions may not have been acquired by this crew.

For both of these reasons it would appear evident that crews should be provided with EIS display familiarisation in the simulator. During such training they would be able to witness a full range of failures, enabling them to acquire the necessary visual and interpretive skills, before being presented with associated problems on an aircraft in flight. It is therefore recommended that the CAA should review current airline transport pilot training requirements to ensure that pilots, who lack experience of electronic flight displays, are provided with familiarisation of such displays in a flight simulator, before flying public transport aircraft that are so equipped (Made 30 March 1990).

2.1.4.2 *Training for flight crew/cabin crew coordination*

It could be argued that the pilots of this aircraft did not make effective use of the cabin crew as an additional source of information. Such co-operation could be encouraged by joint training exercises between flight and cabin crews. In addition, it should be possible to provide simulator exercises in which it would be appropriate for pilots to ask for cabin crew to give a briefing on events in the cabin and for the role of the cabin crew to be taken, in such exercises, by the simulator instructor. Such training would serve to provide pilots with the knowledge that cabin crew are a source of information that should be considered in certain emergencies. Equally, cabin crew could be trained to appreciate that one factor which they should consider during any emergency is the provision to the pilots, in a timely way, of a summary of the sights and sounds witnessed in the cabin. It is therefore recommended that training exercises for pilots and cabin crew should be introduced to improve co-ordination between technical and cabin crews in response to an emergency (Made 30 March 1990).

2.1.4.3 Pilot training

2.1.4.3.1 Technical training

With the increased complexity of modern aircraft systems it has become generally accepted that pilots cannot be expected to have an in-depth technical knowledge of all the systems on their aircraft. In addition, technical development has produced systems with much improved fail-safe characteristics which can give the flight crew continued system performance following anticipated discrete failures within such systems. Because of this technical progress, associated pilot training has become increasingly based on the 'need to know' principle. This approach has its limitations and largely rests on the assumption that all technical failures with which a flight crew may be confronted can be anticipated. This is an unsafe assumption.

In this accident, the pilots were suddenly presented with an unforeseen combination of symptoms that was outside their training or experience. It may be contended that fan/compressor blade contact with the surrounding abradable seals during conditions of severe out-of-balance running could not have been anticipated technically. Even if this is accepted, this effect has now been demonstrated.

It is also apparent that this flight crew did not assimilate the readings on both engine vibration indicators. The reaction of pilots to indications on the flight deck is modified by their general experience and many pilots of earlier gas turbine aircraft have become dismissive of engine vibration indicators due to the inferior performance of such systems. Such views are liable to prevail on modern aircraft unless the technical knowledge of pilots is effectively revised.

The prime factor which appeared to confirm to this crew that the No 2 engine was at fault was the sudden reduction in noise and shuddering which occurred when the No 2 engine was throttled back. It is considered (paragraph 2.2.2.2) that this effect was due to the No 1 engine recovering from a series of compressor stalls, due to the autothrottle disconnection which preceded throttling of the No 2 engine. This is yet another technical systems finding which should be covered in pilot training since it may have implications for engine failure discrimination where the affected engine is experiencing compressor stalls, with autothrottles engaged.

Such findings raise questions concerning the level of technical training available to pilots of modern aircraft. In addition they illustrate the point that such training should also include an appreciation of systems response under abnormal conditions, particularly where the associated symptoms have the potential to mislead flight crews in an emergency situation.

2.1.4.3.2 Decision training

Training of flight crew can be classified under three broad headings. There is training designed to provide the pilot with specific handling or psychomotor skills; that designed to ensure that pilots are familiar with procedures (*eg* the pattern of behaviour required to deal with an engine fire); and that designed to provide the pilot with general techniques for dealing with unexpected and possibly poorly defined problems.

Flying training and checking has traditionally concentrated on the first two types of training, and this accident provides evidence of the efficiency of that training. The aircraft was controlled satisfactorily by the captain, and the engine shut down procedure was carried out with accuracy. Any errors made on the flight deck in this accident were at the highest decision making level. The crew was not presented with a clear cut fire warning, with which they would undoubtedly have dealt satisfactorily, but with a noise, shuddering and the smell of burning. Nowhere in their previous experience would they have been presented with this particular situation, and it was therefore up to them, or at least up to the commander, to formulate a plan for dealing with it.

Because it is not possible to anticipate every emergency or combination of circumstances and reduce such situations to a level at which pilots may be trained to deal with them procedurally, it may be argued that it is the essence of the pilot's task to bring his flexibility and decision making potential to bear on those situations that cannot be anticipated. Such considerations have led to the development of 'Line Oriented Flying Training', 'Cockpit Resource Management', 'Flight Deck Management' and other training concepts designed to provide pilots with experience of evaluating unusual situations, albeit in the flight simulator, in the belief that such practice in making high-level decisions will transfer positively to the real flight deck. Such courses are not presently required for British airline transport pilots, and hence their training tends to contain a heavy procedural bias. This accident emphasises the fact that occasions arise when it is important for pilots to have the ability to evaluate novel situations correctly, and consideration should thus be given to requiring that evidence evaluation and decision training, as well as procedural training, should be included in company training and checking procedures.

It is therefore recommended that the CAA should review current airline transport pilot training requirements with a view towards considering the need to restore the balance in flight crew technical appreciation of aircraft systems, including systems response under abnormal conditions, and to evaluate the potential of additional simulator training in flight deck decision making (Made 30 March 1990).

2.2 Engine failure analysis

2.2.1 *General*

From the engine investigation standpoint, the pre-accident sequence fell into three distinct phases; the initial problem when there was a sudden onset of heavy vibration, shuddering and compressor stalling which ceased after about 20 seconds, referred to as Event 1; an intermediate period during the descent at low power which lasted up to the second sudden onset of severe vibration during a power increase on approach, followed by a sudden thrust loss on the No 1 (left) engine about 50 seconds before impact, referred to as Event 2. During both these events there were reports of flames and sparks emanating from the No 1 engine.

Examination of the engine parameters recorded on the FDR over the previous 25 hours did not reveal any evidence of a significant change in either engine's characteristics. Up to the instant of Event 1, both engines had been performing entirely normally, neither showing any evidence of abnormal vibration levels nor of changes in the N1/N2/EGT relationships. At Event 1, the FDR record showed changes occurring to the No 1 engine parameters only. No changes occurred to the No 2 engine parameters at this time and it was retarded and subsequently shut down, having displayed normal indications at all times.

After the initial period of heavy vibration and stalling on the No 1 engine, the FDR record showed that, when this engine had restabilised there was only a small change in engine thrust. There was, however, a marked increase in vibration level on the No 1 engine, saturating the indication system at high fan speed, but reducing to fall within the measurable range (less than 5 units) after the fan speed was reduced to 33% during the descent. These levels were consistent with those produced by an engine with a fan which had one blade outer panel missing when compared with the data derived from engine testing (see paragraph 1.16.1) and that later available from the FDR record from the blade failure on G-OBMG (paragraph 1.17.7.3). There had also been a loss of overall engine efficiency, indicated by a higher EGT/N1 ratio compared with that required before Event 1. The vibration levels induced by the imbalance caused by the loss of a fan blade outer panel on the No 1 engine would have resulted in tip rubbing of blades throughout the compressor at the high N1 (97%) recorded immediately after Event 1. This would have led to a loss of compressor efficiency, which would have required the combustion temperature to have risen in order to supply sufficient energy to the LP turbines to drive the fan.

Between the time that the No 1 engine stabilised and Event 2, this engine responded, apparently normally, to the applied throttle demands. It continued, however, to exhibit abnormally high vibration levels for the power settings used and these levels were considerably above those exhibited at any power setting before Event 1 (see Appendix 4, fig 4). It also continued to operate with a raised EGT/N1 ratio although, without the indications of a similar undamaged engine for comparison, these changes would not have been obvious.

Just before Event 2, the No 1 engine initially responded to an increased throttle demand by increasing its fan speed to 70%. Rapid changes in engine parameters then occurred, after which N1 and N2 decayed, the exhaust gas temperature (EGT) increased slowly and the engine ceased to respond to the throttle. The engine then remained, seemingly locked, in this condition until the end of the FDR record (see Appendix 4, fig 3).

Strip examination of the No 2 engine (paragraph 1.12.2.1.1), including the MEC, revealed only damage which was consistent with the effects of ground impact, with the engine either stopped or windmilling very slowly. No evidence was found of any pre-existing imbalance, nor of any fire. This accorded with the FDR record which showed that the engine had been first retarded, and subsequently shut down, without any performance or vibration excursion having occurred.

By contrast, the strip examination of the No 1 engine (paragraph 1.12.2.1.2) showed that, although the damage resulting from ground impact was very similar to that observed on the No 2 engine, there were marked differences in its condition. The fan and fan case showed evidence of fan break-up at high energy and there were two areas of fire damage. There was also a great deal of rubbing damage to the rotating seals and blade tips of all compressor stages, consistent with this engine having run at considerable power, with a very high level of vibration. No evidence was found of imbalance due to whole or part blade loss in any rotating stage apart from the fan, nor was there any bearing distress to account for the vibration levels recorded. There was evidence of hard object ingestion throughout the compressors and of wood ingestion through to the turbine section, where it had been charred. This wood ingestion showed that the engine had been running right up to the time of impact, with combustion still being sustained.

2.2.2 *No 1 engine failure sequence*

2.2.2.1 *Fan failure sequence*

On reconstruction of the No 1 engine fan, it was established that, although all fan blades were found to have fractures or damage of some type, only the fracture of blade No 17 exhibited the characteristics of fatigue. If this fracture had occurred first, the initiation of Event 1 would have been the sudden separation of a single fan blade outer panel. This would have induced a localised disturbance in the fan airflow, coupled with severe imbalance, both of which can cause the onset of a fan stall, and subsequently a booster and core stall. (see paragraph 1.17.6.3). The severe imbalance would also have caused blade tip and air-seal rubbing throughout the engine, with a consequent degradation of the engine stall margin. The rubbing of the fan and booster blades on the abradable tip path seals would have generated a considerable amount of acrid smelling products. These would have been entrained into the core engine and thence, through the bleed air system, into the air conditioning. The reported smells of 'rubber' and 'hot metal' would have been consistent with such effects.

Appendix 4, fig 10 shows that the initial reaction of the No 1 engine of ME to the first event was almost identical to that of the No 2 engine of MG, which is known to have suffered a fan blade outer panel separation, with very little subsequent damage. It can be seen that the No 1 engine of ME almost restabilised during Event 1 about 6 seconds after the onset of compressor stalling, but it appears that the power set at that time was greater than the engine, with its then degraded stall margin, could sustain and it entered a series of stalls which lasted about 20 seconds. The autothrottle was disconnected about 20 seconds after the onset of Event 1 and at a moment when it had set a slightly lower throttle angle than that which had been required for the rated power climb. This reduction in power demand appears to have enabled the No 1 engine to recover from its compressor stalling. The stall sequence and the recovery from it are examined in detail in paragraph 2.2.2.2. Subsequently, the vibration levels on the No 1 engine of ME at reduced thrust were comparable to those experienced on the No 2 engine of MG under similar conditions. These similarities indicate that, after Event 1, the No 1 engine fan of ME was in a comparable state to that of the No 2 engine of MG. The continued operation of the No 1 engine of ME, after such a fan blade failure, may be understood when compared with the result of the test on an engine which had one fan blade outer panel missing (paragraph 1.16.1) which showed that there was no detectable loss of performance or efficiency in this condition.

Thus all the No 1 engine symptoms at Event 1 were consistent with the instantaneous loss of the outer panel from one fan blade and the presence of a fatigue fracture on blade No 17 alone indicated that this was the first event. The comparability of the vibration levels with those of MG and the maintenance of power after Event 1 suggested that the No 1 engine fan had suffered very little damage apart from the loss of one outer panel at that time. This implied that the separated panel had either passed through the fan, like that on MG, or had become embedded in the acoustic liners of the fan case, or intake duct forward of the fan.

Between the end of Event 1 and the occurrence of Event 2 there was no evidence of any significant change in the condition of the No 1 engine. Since this engine was being operated at reduced RPM during the descent, compared with that at the time of Event 1, it was unlikely that the rotor blade tips, or the rotating seals, would have rubbed further than they had during the first event. This also implied that the fan had suffered no significant additional damage between the two events. At Event 2, the condition of the No 1 engine clearly deteriorated abruptly. Since the strip examination of this engine did not reveal any catastrophic failures in the booster, core engine or LP turbines, nor any malfunction of the fuel control system, this change would appear to have been the result of additional fan damage. The finding, on the ground below where Event 2 took place, of fragments of at least three fan blades, including parts of blade No 17, together with parts of acoustic liner and their attachments, also indicated that the cause of this deterioration was additional fan damage.

Since blade No 17 was the only fan blade to have suffered a fatigue failure, it was concluded that the initiating occurrence for Event 2 must have been the ingestion by the fan of a foreign object. The finding of parts of blade No 17 outer panel under that part of the final approach path where Event 2 occurred suggested that the release of this outer panel from a place of entrapment was the most likely cause of the additional fan damage. This view was supported by the condition of the fan on the Dan Air engine (NL incident) in which outer panel separation caused immediate massive fan damage, albeit at a higher power setting than that applicable to Event 2. The behaviour of the Dan Air engine after the blade outer panel separation suggested that the resulting airflow with such fan damage is likely to induce a 'locked compressor stall' unless engine power is retarded, and even then it might not be possible to re-establish any significant power.

The exact sequence of the fan failure at Event 2 was difficult to analyse in the light of the additional damage suffered by the fan during impact with the motorway. The presence of fragments of blades 4 and 5 at the location of Event 2, combined with the severe overheating observed on the blade 6 outer panel suggested that blade 6 outer panel detached at this juncture and became trapped between the fan blade tips and the abradable liner. This was the most likely origin of the 'fire' in the intake reported by many witnesses and the associated sparks would also have constituted a potential source of ignition for both fire zones by penetration of the intake duct into the fan case cowl and by passage down the fan exhaust to ignite fuel and oil atomising from the trailing edge of the bypass duct.

2.2.2.2 *Recovery of the No 1 engine from the series of stalls at Event 1*

The timing of the recovery of the No 1 engine from its series of stalls was clearly crucial to the crew's understanding of their situation. The influence of throttle lever angle (TLA) on the ability of the engine to recover and how the autothrottle affected the throttle position has thus to be considered.

Appendix 4, fig 11 shows the relative variation of a number of parameters over a period of 35 seconds, starting 4 seconds before Event 1. The parameter traces shown are as recorded, without offsets for mechanical or electronic delays. There is approximately a 0.5 second delay in N1, but autothrottle position lag is not readily estimated, as it is mainly a mechanical hysteresis dependent on the movement demanded. However, all the parameters shown were sampled at a rate of 1/sec. and as a result, the actual peak and trough values may not have been recorded. This is particularly true of N1 and, to a lesser extent, throttle position (TLA recorded at the MEC input lever) on the No 1 engine which was changing, in both value and sense, very rapidly. Therefore, to give some idea of what the extreme values of N1 might have been, the slopes have been extended (in broken lines) where the peaks and troughs obviously have been truncated.

Examination of these parameters and relating them to the autothrottle logic in use at the time (paragraph 1.17.6.4) has shown that, after making due allowance for the various lags, the autothrottle has reacted correctly to the N1 excursions, in accordance with its design. The loss of the actual maxima and minima, and the hysteresis lag, of TLA is demonstrated by the apparent reduction and subsequent increase of TLA after the autothrottle was disconnected and just before the engine settled at the reduced N1. It is possible that TLA reduced to an angle of as much as 1° below that recorded in response to the combination of N1>10% below target but increasing towards the reduced N1 target very rapidly. Whilst at this condition, the 4th stall occurred and the autothrottle was then returning TLA to the position of the reduced target N1, since N1 was no longer increasing.

This resulted in the throttle lever coming to rest, with the autothrottle disengaged, at the reduced target N1 appropriate to the logic law which prevents overboosting of an unresponsive engine. With the gas path degradation caused by the fan damage, the engine would have had reduced responsiveness. This reduced TLA position therefore most probably prevented a large N1 overswing and permitted the engine to recover and stabilise.

It can be seen at Appendix 4, fig 11 that the closing of the No 2 engine throttle coincided almost exactly with the start of the final stall recovery acceleration of the No 1 engine, which would have become smooth running (apart from the imbalance vibration) at that instant.

The evidence thus indicated that it was the disengagement of the autothrottle at a time when it had, whilst operating correctly, demanded a reduced TLA which permitted the stable stall recovery of the No 1 engine. This caused the closure of the No 2 engine throttle lever to appear to coincide with the cessation of the shuddering from the No 1 engine.

2.2.3 Cause of fatigue initiation in fan blade No 17

The metallurgical examination of this blade established that the fracture had propagated initially by fatigue, the origin of which appeared to be on the pressure face of the blade about 1.25mm aft of the true leading edge. The transference of the original leading edge and pressure face surfaces to the adjacent blades, as a result of inter-blade clashing, made it impossible to identify any surface feature which may have led to fatigue initiation. However, the depth of the material removed from the pressure face indicated that if there had been an anomaly at the origin of the fracture it must have been only very small (see Appendix 1, fig 3).

During the initial part of the investigation, the manufacturers were convinced, by the work that they had done during the engine type certification, that there were no severe blade vibration modes anywhere in the operating envelope of the fan in the absence of serious blade distortion. The possibility that bird or other foreign object damage might have caused sufficient blade damage and distortion to account for fatigue initiation and growth to critical length between Events 1 and 2 was explored, but engine testing with damaged and distorted blades did not reveal sufficient vibratory excitation at the powers used during the flight. It was also concluded that such damage would have had to be so gross that it could not have been present on the blade before Event 1 without revealing itself as loss of fan efficiency and/or engine vibration or, if it had been present before take-off, being visible during the normal pre-flight inspection. Thus the initial conclusions reached were that the pressure face had suffered a small but particularly sharp surface damage feature with a large k_t, that there was insufficient information available from the fracture surface to indicate how long such a feature had existed and that it was an isolated failure.

However, after metallurgical examination of the two fan blade fractures suffered by G-BNNL and G-OBMG had revealed a number of features common to each other and to that from ME, it became clear that there was a generic problem affecting the –3C-1 variant of the CFM 56. Both of the later fractures had originated at the base of the shot-peened layer on the blade pressure face, close to the mid-chord position and just above the leading edge of the mid-span shroud. There was no detectable evidence of any surface damage nor of any metallurgical or microstructural deficiencies in either blade. The examination also revealed that once the fatigue had initiated, it had progressed to its critical length and final rupture extremely rapidly, taking three flights to complete separation in the case of the NL, and only two in that of MG.

The position of the fatigue origins was in the region of the blade where the highest vibratory stresses were expected for one particular vibratory mode but, on the basis of the data collected during the certification testing, these had been shown to be well below the manufacturer's reduced endurance limit. Initiation of fatigue at the base of the compressive layer below shot peening is typical of the result of cyclic loading at stress levels above the endurance limit and the very high initiation/propagation time ratio indicated that this level was only just above the endurance limit. This implied that the fan blades had been subjected to an hitherto unsuspected blade vibration.

Comparison of the two later fractures with that from ME showed that although the fatigue origin on the ME blade was near the leading edge, the planes of all three fractures ran very close together. (See Appendix 1, fig 8) This suggested that all three failures were the result of the same problem. Examination of the blade vibration modes established during certification revealed that the nodal line indicated by the planes of the three fractures matched, amongst others, that to be expected from a second order system vibration mode[5]. Furthermore, a comparison of the stress levels induced by this mode in the leading edge zone, relative to those at mid-chord, indicated that a defect with a k_t of as little as 2.5 could render the leading edge as sensitive to fatigue nucleation as the mid-chord zone. Thus, since a score with a semi-circular cross section which ran chordwise across the blade surface would have had a k_t of 3, a relatively minor defect resulting from FOD would be sufficient to move the natural initiation zone from the mid-chord to the leading edge when the fan was subjected to this mode.

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[5] Blades and disc vibrating as an entity

2.2.4 *Source of vibratory stresses*

At the time that the CFM 56–3C-1 came into service, the manufacturers had satisfied themselves and the certificating authorities that the type met all the airworthiness requirements, amongst which was the requirement to ensure that all blade stages were free from 'unacceptable vibratory stresses'. (See Appendix 1, extract 1) This had been demonstrated by reference to all the past testing of blades and test bed running of strain-gauged engines. This latter testing, even when done with –3B variants, had required the engines to be run at physical speeds considerably above those which were permitted in flight, even for the –3C–1. These tests had demonstrated that throughout the engine speed range there were only synchronous responses and these produced acceptable vibratory stresses. However, in order to reach the very high fan speeds required for certification whilst testing at sea level, it was necessary to use a variable fan nozzle to avoid driving the core engine beyond its limits. By doing this, the airflow through the fan becomes unrepresentative of that which actually occurs at high altitude as the fan is working on a different operating line. It was believed, however, that any instability features which existed would show up, albeit at reduced levels, and if they did so, then a more representative test would have to be undertaken to establish the actual stresses created. Not having observed a tendency to produce any instabilities at sea level, the manufacturers and certificating authorities were satisfied,and no tests were performed on a strain-gauged engine in an altitude test cell, or in flight.

After the two later fan blade fatigue fractures, it became suspected that the fan was being subjected to higher vibratory stresses than were thought to exist. The fact that all three fan blade fatigue fractures had occurred across the same blade section, at similar flight conditions of engine speed and altitude and that all three engines had completed a similar number of flight cycles (although significantly higher running hours in the case of the Dan Air engine), indicated that there was an unique vibratory mode involved which was excited regularly. On comparing the operating conditions to which the –3C-1 was exposed with those of the –3B–2, there were only two areas of significant difference; the take-off thrust and the rated power climb thrust. Since take-off thrust is only used at relatively low altitudes, it was believed that test bed running accurately reflected true operating conditions. It appeared more likely, therefore, that the excitation occurred during rated power climb at a considerable altitude, a regime in which the true airflow conditions were known to be different from those tested up to that time.

In order to achieve the high physical fan speeds necessary on a test bed to simulate more accurately the high corrected fan speeds at altitude, it was necessary to run the core engine to speeds and temperatures which considerably shortened its life. The initial test bed running directed at exposing any unknown vibrations revealed some non-synchronous vibratory excitation of the fan. A review of the vibration survey made during the modified splitter tests, conducted after the accident to ME and unrelated to the investigation, then also revealed what, in retrospect, was a small indication that the problem existed.

Following the test bed research, the strain-gauged blade tests conducted on a flight test engine confirmed the presence and mode of the vibratory response and showed that it could produce stress levels approaching the endurance limit.

2.2.5 *Failure of the certification process to reveal vibration*

The CFM 56 was originally certificated jointly by FAA and DGAC as being in compliance with the requirements of FARs and JARs. With regard to the requirement to demonstrate freedom from damaging vibration, CFMI had adopted the normal US manufacturers' approach and had tested a strain-gauged engine in a sea level test cell. As this test had not revealed the presence of any such vibrations, the FAA and DGAC accepted that the engine had been demonstrated to have met the requirements of both FARs and JARs. Because of their reciprocal validation agreement with the FAA, the CAA also accepted the type certification of the CFM 56-3C

The tests performed, after the two later incidents, on strain-gauged engines in the flying test bed showed that the previously undetected system mode vibration of the fan was consistently excited when using -3C rated climb power above 10,000 ft. Although none of the measured vibratory stresses on the fan blades resulting from this excitation were above the endurance limit, they were sufficiently large to suggest that, with the anticipated variation of excitation of individual blades within a fan, some blades might experience stresses at, or above, this limit.

Had a similar flight test been performed during the certification testing, the manufacturer and certificating authorities would have become aware of the vibration mode and the engine could not have been considered acceptable for introduction into service before the characteristic had been eliminated.

Previous certification history, on other engine types, had suggested that such characteristics would reveal themselves, to a degree, during sea level testing. It appears, however, from the experience of this accident, and the two subsequent incidents, that this was not a safe assumption since the level of blade excitation was so low as to be masked by the background signal 'noise'. Although it will continue to be necessary to attempt to identify potentially hazardous modes using refined procedures on heavily instrumented ground test engines, only by test in the real operating environment can the actual excitation levels be reliably ascertained.

It is therefore recommended that the type certification requirements for gas turbine engines should be amended so that it is mandatory to perform instrumented flight tests to demonstrate freedom from damaging vibratory stresses at all altitude conditions and powers which an engine will encounter in service (Made 30 March 1990).

2.3 Fire

2.3.1 Source of fire

The first indication of fire in the No 1 engine nacelle occurred shortly after Event 2 in the fan failure sequence when there was evidence from both the FDR and CVR that a fire warning had been triggered. Although the fire warning was not related to the No 1 engine by the FDR evidence, it was by the subsequent conversation between the commander and first officer recorded on the CVR.

The examination of wreckage on the accident site indicated that only the No 1 engine and nacelle had evidence of fire damage and the more detailed examination revealed that there was no evidence of fire elsewhere on the aircraft. Examination of the No 1 engine and nacelle revealed that there were three separate and distinct fires which had occurred on this power plant. Of these, two were in zones monitored by fire detection loops, one on the outboard side of the fan case and the other on the underside of the combustion case. Neither had evidence of the presence of any forcing air draught to show that they had been burning in flight. The third fire had been on the outside of the nacelle, on the outboard side of the reverser duct, remote from any detectors. This fire showed the characteristics of having been slipstream driven and must have been burning whilst the aircraft was in flight.

Since the fire on the outboard side of the reverser duct was in an unmonitored zone, it is highly unlikely that it could have triggered the warning. Thus, since the warning had been triggered in flight, there must have been fire or very hot gases present in one of the other two zones. The fire on the underside of the combustion case, although in a monitored zone, had been very minor and showed the characteristics of a restricted fuel ground fire. It was also seen that this fire centred on a fractured fuel nozzle fitting which had clear evidence of having been damaged during the ground impact sequence, indicating that this fire was entirely post impact. Thus the fire warning must have been triggered by the fan case detectors.

The fan cowling itself is a nominally enclosed space, the only venting being via the cowl drain at the bottom, just ahead of the cowling firewall. Thus, even if the intake duct were breached by fan debris, it is unlikely that there was a fast airstream through the fan cowl in flight. The ground fire which had affected the fan case after the aircraft had come to rest had consumed a large proportion of the forward cowling and had overlaid any evidence, on the outside of the fan case, of any fire which might have occurred in flight. The reconstruction of the cowling, however, showed that some areas of the forward cowl which had broken free at impact had not been involved in the ground fire. By positioning these pieces it was possible to show that a fire had been present in the fan cowl before it had been broken up by impact and that fire appeared to have been present on the outboard side of the fan case and above the level of the MEC.

The investigation of the two other engines involved in fan blade fatigue failures showed that fuel pipe unions and the seal between the HP fuel pump and the MEC were susceptible to being loosened to the point of leaking if subjected to severe vibration. Furthermore, the trials performed to try to establish the characteristics of such leaks showed that atomised fuel spraying could occur as the result of unions being loosened to the extent found with the fuel pressures to be expected whilst the engine was running.

The exposure to vibration of the 3 engines which suffered fan blade fractures was compared. It was observed that the No 2 engine from MG had suffered a brief initial period of very high vibration at a high power setting, under similar conditions to that seen on the No 1 engine of ME but of about half the duration. Thereafter the engine was throttled back to a flight idle setting for a similar duration to that experienced by the ME engine during the descent. During the approach to East Midlands, the ME engine experienced two exposures to higher vibration levels as a result of engine power being increased. Thus the No 1 engine of ME had experienced greater exposure to vibration than the No 2 engine of MG and was likely to have at least as much loosening of pipe unions. Consequently, since the fuel unions found on the MG engine were sufficiently loose to produce atomising spray leaks, it is probable that immediately before Event 2 , at the time of the second power increase, atomised fuel sprays were present in the fan cowl of the ME engine.

If such leaks were present with no ignition source, the free fuel would have run to the base of the cowling and escaped through the vent and drain apertures. The airstream around the outside of the nacelle flows upwards and outboard, the upwards component increasing with angle of attack. The evidence of fluid streaking running in this direction showed that a significant quantity of fuel and oil, which could also have been liberated by a similar union loosening process, had been present in flight. When the fluid on the outside of the nacelle reached the trailing edge of the cowling, it would have been drawn off as a highly combustible atomised mist by the slipstream.

The source of ignition for the fluid mist from the trailing edge could have come from either the flames resulting from compressor stalling passing down the fan stream or incandescent fan blade particles generated by the fan break-up at Event 2. The same potential sources could also have ignited fuel sprays within the fan cowl if the inlet duct had been breached. Although no evidence remained to demonstrate that it had been, the likelihood of a breach being made by fan break-up fragments is reasonably high, and no evidence was found of an alternative ignition source within the cowl.

2.3.2 *Potential effects of fire*

Although the effects of the fire were restricted to the No 1 engine and nacelle, this was principally due to the fact that the airfield fire service was able to attack it with appropriate extinguishants before it had time to spread. Had it been a significantly longer time before fire fighting was possible, although there was very little fuel spillage from the aircraft, it is probable that a much greater loss of life would have resulted.

The likelihood of a post crash ground fire will be much greater if there has been fire on an aircraft in flight. Fuel or oil leakage from loose pipe unions is an ever-present hazard and will always increase the possibility of a fire in flight.

It must be accepted that the vibration levels experienced on the No 1 engine of ME were orders of magnitude greater than those normally present and, therefore, more likely to cause loosening of pipe unions. However, it is under such conditions that there is likely to be an increased risk of accident. Although the fitting of locking wire to pipe unions would not entirely prevent loosening of these unions, it would limit the degree of looseness and, consequently, the likelihood of an atomised spray with a higher susceptibility to ignition. The fuel and oil pipe unions on the fan case of the CFM 56, in line with current practice, are not generally wirelocked; the control air pipes are the only ones, in this zone, wirelocked as a matter of course.

Although wirelocking of pipe unions will not prevent leakage of combustible fluids completely, its benefits and shortcomings should be reviewed in relation to the potential reduction of fire hazards in vulnerable zones. It is therefore recommended that the potential for fuel and oil system leakage within the fan case area of high by-pass turbofan engines, during conditions of excessive vibration, should be reviewed by the engine manufacturers and the CAA with a view towards modifying such systems to minimise such leakage and the associated fire risk (Made 30 March 1990).

2.3.3 *Fuel tank integrity*

The other major factor which affected the post-crash fire was the lack of a major release of fuel in the impact. This was partly due to good fortune, in that the centre section fuel tank, which was ruptured, did not contain fuel for this flight and that the damage to the left wing-tip occurred outboard of that fuel tank. It was, however, more largely due to the continuing integrity of the wing fuel tanks further inboard,which did not rupture despite the separation of both main landing gear (MLG) legs and the almost complete separation of both engines.

The wreckage showed that both MLG legs separated entirely consistently with the crashworthiness features of their design, failing the fuse-pin bolts and leaving the rear wing spars intact. In the case of the engines, the structural failures occurred within the pylons themselves, leaving the fuse-pin bolts in place; the separations were, in this instance, benign and the forward wing spars were not disrupted.

The excerpts in paragraph 1.17.16 are from the applicable airworthiness code (BCAR Section D) and the current code (JAR-25). They concern fuel tank penetration and address the MLG failure mode case (JAR-25.721) and the rear-mounted engine case. However, they do not address, other than in very general terms, the case for wing-mounted podded engines such as on the Boeing 737-400 and similarly configured transport aircraft. It is recommended, therefore, that the CAA should review the existing Joint Airworthiness Requirements concerning fuel tank protection from the effects of main landing gear and engine detachment during ground impact and include specific design requirements to protect the fuel tank integrity of those designs of aircraft with wing-mounted engines. (Made 30 March 1990)

2.4 Aircraft systems.

2.4.1. *Aircraft systems-general.*

Evidence from both the FDR and the flight crew did not indicate that there were any abnormalities connected with the flying controls, fuel or hydraulic systems which could have contributed to this accident. Accordingly, the systems examination was largely confined to those areas which could have had a bearing on the crew's perception of the failure in the No 1 engine.

In addition to the integrity and function checks of the EIS and associated wiring, *the fire/overheat detection system and the vibration monitoring system*, some tests were also performed on the air conditioning system.

2.4.2 *Air conditioning system.*

As referred to in paragraph 2.1.1.1, the commander stated that his knowledge of the air conditioning system had led him to believe that the problem lay in the No 2 engine. Thus, although it has since been established both by analysis and by the study of similar incidents of severe fan imbalance that smoke and/or fumes may be expected to be emitted from the abradable engine seals, it was considered prudent to ascertain that the air conditioning system itself had not generated smoke. Although smoke or smells of burning perceived in the aircraft could have come from a number of sources, the sudden perception of such indications, coupled with vibration might have indicated a problem in one of the rotating components in the air conditioning system and it was for this reason that the air cycle machines and the circulation fans were selected for examination. No evidence of pre-impact failure was found.

2.4.3. *Engine fire and overheat detection system.*

The discovery, during testing, that the fire detection module exhibited the 'latch-up' phenomenon (paragraph 1.12.2.3) raised the question as to whether the system may have been dormant during a period in which a fire had occurred in No 1 engine and thereby denied or delayed a fire warning to the crew. This was not considered likely for two reasons. Firstly, the evidence of airborne fire on the No 1 engine was consistent with it being of short duration, compatible with the period of time that elapsed between the fire bell being heard on the CVR and impact with the ground. Secondly, had the fire been burning at an earlier stage with the detection system latched-up then it would not have provided a fire warning at all once the system became unlatched.

Apart from this discrepancy, no other faults were found in the fire and overheat detection system. The wiring associated with the system was also found to be connected in the correct left/right sense.

2.4.4 *Performance of the AVM system.*

The AVM was designed to detect radial accelerations at a frequency corresponding to the speeds of the rotating engine assemblies. It will not detect vibration which is outside a narrow band of N1 or N2 speeds such as, for example, that induced by engine stalls or aerodynamic effects on individual blades. This was necessary to achieve the freedom from spurious alerts which were a feature of the older generation of vibration warning systems and which contributed to a loss of confidence in such systems.

The various tests which were carried out on the equipment fitted to ME (paragraph 1.16.3) were performed to establish not only that it was serviceable according to its specification, but also that it was, by design, capable of providing information to the crew of the accident aircraft during the critical early phase following the fan blade failure in the No 1 engine.

The conclusion of the tests was that the AVM system was serviceable and should have been indicating a full-scale reading on the No 1 engine vibration gauge within about 2 seconds of the fan blade outer panel separation occurring. Subsequent incidents of fan blade separation (see paragraph 1.17.7) confirmed this behaviour. However, in the two incidents which involved fan/compressor damage caused by bird ingestion (paragraphs 1.17.8.1 & 1.17.8.2) the crews reported significant delays in presentation of associated readings on the vibration gauges, even though vibration was obvious to the crews.

The reasons for such occurrences were not clear and, if it were to be argued that birdstrike damage is analogous to the blade separation case, then it would appear to have pointed to some unexplained deficiency in the AVM system performance. Further consideration, however, indicated that the two situations are not directly comparable as birdstrike damage seldom involves significant loss of mass of the rotating assemblies, although it may distort the fan/compressor blades.

The birdstrike tests conducted on a CFM 56-3C-1 engine during the course of the certification testing of the modified fan blades confirmed the non-linear response of the engine to an imbalance with variation of fan speed.

The recorded vibration levels resulting from a birdstrike were low (within the measurable range of the AVM gauge) showing that the actual imbalances were small. With the 'dip' in the engine sensitivity to imbalances which occurs at around the take-off RPM range, some engines might have virtually no response to these small imbalances. Since, however, the engine sensitivity to imbalance rises rapidly with reducing fan speed, the vibration and its indication would rise as the engine thrust was reduced. For the much higher imbalances encountered with a fan blade outer panel separation it is considered that the response, even at the minimum of the dip, would still produce close to maximum reading on the vibration gauge. The once per revolution impulses, detected during the tests, could well give rise to perceptible vibrations, although they would not be indicated.

2.4.5. *Engine instrument system.*

The series of tests of the primary EIS conducted or supervised by AAIB showed beyond any reasonable doubt that, not only was the unit serviceable, but the data recorded on the FDR was a subset of the information displayed to the crew. This confirmed that the data points on the FDR were displayed on the EIS but, because of the limitations of the FDR sample rate, extra points also existed which could not be recalled.

Establishing actual values or precise behaviour of the instruments during the critical early stages of the first event are of little importance beyond showing that significant fluctuations of the primary indications, particularly N1, did occur during this period. This was demonstrated.

The performance of the EIS during the blade separation incident to G-BNNL (paragraph 1.17.7.1), in which the commander reported that his primary engine instruments apparently showed no abnormalities despite the fact that the FDR recording indicated rapidly decaying primary parameters as the engine ran down, remains unexplained. A theoretical analysis could find no failure case in which data recorded on the FDR could differ significantly from that displayed on the EIS, and testing of the units from ME revealed no such behaviour. It should also be borne in mind that each primary parameter is served by its own microprocessor and circuitry and any suggestion that some obscure fault could have affected all four parameters thus appears highly improbable.

The only secondary parameter of importance to this investigation, namely vibration, is discussed in paragraph 2.4.4. There was no evidence that the technical performance of the secondary EIS unit affected the flow of information available to the crew of ME.

Checks on the wiring to and from both EIS units found no signs of incorrect connection with regard to left/right sense.

2.4.6 *Airborne closed circuit television monitoring*

The accident would probably have been averted if the pilots had been able to observe the pulsating flames and blue sparks which emanated from the No 1 engine after the primary fan blade failure and which were clearly apparent to many in the passenger cabin.

The technology is currently available to provide flight crews with an external view of major areas of their aircraft by means of closed circuit television. Internal zones such as cargo bays and areas of the passenger cabin can also be covered. Such a facility would enable the flight crew to assess various types of external problem such as fire, landing gear status, airframe damage, icing etc. Internal coverage would provide an additional means of assessment of cargo bay problems and cabin status, in addition to ground security monitoring.

This accident has also highlighted another area in which the availability of television monitoring could have benefit. With the increasing use of electronic 'glass-cockpit' display technology the facility to process information, prior to its display, has been greatly enhanced. This can improve the presentation of information to a crew and, importantly, can also be used to greatly assist their decision-making by giving them computer-assisted diagnosis. With such improved information techniques however it becomes increasingly vital to be able to demonstrate, during any post incident/accident investigation, the displayed information with close fidelity. This may present problems depending upon the type of signal processing employed, and particularly where the sensors have been attempting to 'track' an abnormal situation. In short, the question which arises concerns whether the information displayed to a crew may always be faithfully replicated after an incident. It is therefore considered that it would greatly benefit future crews and associated investigations if all such displayed information were recorded by means of television monitoring coverage of the flight deck. If, in addition, a playback facility were included, pilots could recall instrument display information after acting to contain an in-flight emergency.

It is therefore recommended that the CAA should expedite current research into methods of providing flight deck crews of public transport aircraft with visual information on the status of their aircraft by means of external and internal closed circuit television monitoring and the recording/recall of such monitoring, including that associated with flight deck presentations, with a view towards producing a requirement for all UK public transport aircraft to be so equipped (Made 30 March 1990).

2.5 Flight recorder design requirements

The system of recording using temporary buffer storage as employed by the UFDR can mean that at impact, if the contents of the buffers have not been transferred onto the recording medium, then that information will be lost. In the UFDR this can be up to 1.2 seconds of data. In this instance a knowledge of the impact parameters was important to the survivability investigation. The loss of the last moments of data meant that the impact parameters had to be estimated. The lost data in the buffer may have yielded more accurate information. If a recorder has to employ a temporary buffer storage, that storage medium should be made non-volatile (*i.e.* recoverable after power off) and contained within the armour protected enclosure.

The European Organisation for Civil Aviation Electronics (EUROCAE) are at present formulating new standards[6] for future generation flight data recorders; these standards will permit delays between parameter input and recording of up to 0.5 seconds. These standards may be adopted worldwide and do form the basis of the new CAA specifications for flight data recorders. It is therefore recommended that the manufacturers of existing flight data recorders which use buffering techniques should give consideration to making the buffers non-volatile and hence recoverable after loss of power, and EUROCAE and the CAA should reconsider the concept of allowing volatile memory buffering in flight data recorders (Made 30 March 1990 and also included in AAIB Report No 2/90).

Because of the length of time (64 seconds) between successive samples of the engine vibration, it was not possible to be precise about when vibration levels increased or decreased. Whilst this is not a parameter that the CAA specifications require to be recorded, it is recommended that, where engine vibration is an available parameter for flight data recording, the CAA should consider making a requirement for it to be recorded at a sampling rate of once per second (Made 30 March 1990).

2.6 Survival aspects

It was apparent from an early stage of the investigation that the first impact of ME, at the top of the motorway eastern embankment, caused much less damage to the airframe than the second impact, at the edge of the western carriageway. This was confirmed by the ground impact marks, by the KRASH analysis and by the items of wreckage which became detached before the second impact. It was thus the second impact which caused both of the major fuselage failures and the separation of the engines.

The lack of any indication of the velocity between the impacts from either the FDR or the cockpit instrumentation prevented an accurate determination of this velocity, but analysis of the trajectory gave a velocity of between 80 and 100 kts at the second, and major, impact (paragraph 1.12.1.1).

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[6] Minimum Operational Performance Requirement for Flight Data Recorder Systems Ref:- ED55

2.6.1 *Injuries*

The initial injuries that occurred were caused by the impact of a seat occupant into the back of the seat in front. In those areas where the floor structure, and hence the seat attachment, failed the initial injury mechanism was compounded by secondary impacts of the seat occupant with loose seats and passengers, and other parts of damaged aircraft structure.

The injuries suffered by the passengers sitting in seat rows 10-17 and 25-27 (paragraph 1.13) clearly show both the advantages of being retained in a fixed seat and the limitations of sitting in a forward facing seat restrained only by a lap belt. Virtually all the passengers suffered from severe bruising under the lap belt and five passengers sustained iliac fractures as a direct result of lap belt loading.

In addition to the results of direct loading of the pelvis by the lap belt the following generalised injury mechanism occurred. As the seat occupant moved forward, the knees contacted the back of the seat in front, loading the knee and the upper leg. This transmitted load back into the pelvis causing a variety of injury, including dislocation of the hip, fracture of the hip joint and fracture of the pelvis. Fractures of the femur occurred as a result of the combination of axial and bending loads induced by the front cross bar of the seat as well as contact with the back of the seat in front. Depending upon the position of the lower leg, damage was caused to the knee as the upper leg moved forwards in relation to the lower leg. In a similar manner, where the foot was fixed by contact with aircraft or seat structure, the foot and ankle also sustained injury as the lower leg moved forward in relation to the foot and ankle, causing a combination of torsional and posterior dislocation injuries.

Gross lower leg fractures occurred where the seats failed and the lower legs were trapped and subjected to secondary impacts.

The overall mechanism is illustrated in Appendix 5, fig 4 (computer simulation of occupant response).

Head and chest injury occurred even where passengers had adopted the crash position and some passengers who rested their heads on their forearms prior to the impact fractured their forearms as a consequence. Some other passengers braced themselves by placing their extended arms onto the back of the seat in front and some of them suffered fractured upper arms and shoulder joints in consequence.

The child seated on his mother's lap in seat 3F sustained major head and limb injuries as a result of the accident and the mother sustained major injuries, some of which were suggestive of having been caused by forcible flexion of the mother over the child during the impact.

It has not been possible to determine the role of the overhead bins in the causation of head injury. The majority of the bins were necessarily removed by the rescuers and there was no evidence to show whether or not either the bins or their contents had been in forcible contact with any of the aircraft occupants.

2.6.2 *Occupant simulation*

The simulation (paragraph 1.16.5) offered additional insights into the injury mechanisms. Measurements of the seat belt webbing stiffness showed a mean elongation of 14% ±4% at 11 kN load. This variation was greater than that permitted in automobile applications and can have a significant effect on occupant kinematics and femoral axial load.

A further point noted was the effect of the tubular spar across the front of the seat as a source of loading of the femur in bending. The new FAA and JAA regulations (paragraph 1.17.11) concentrate on femoral axial loads induced when knee contact occurs with the seat in front, but the simulation showed that femoral bending loads were significant and were considerably affected by occupant position (paragraph 1.16.5):

Upright occupant:	femoral axial	3.4 kN
	femoral bending	1.3 kN
Braced occupant:	femoral axial	2.3 kN
	femoral bending	2.7 kN

The greater vertical femoral load results from the shift of body mass in the seat caused by the adoption of the brace position.

The computer graphics showed that the unrestrained head and torso were free to pivot around the lap strap and impact the back of the seat in front, giving rise to chest, upper limb and head injury. The simulation indicated that Head Injury Criterion (HIC) values of 278 for the braced individual compared with 974 for the unbraced passenger. This value of 974 is just below the HIC 1000 value which is used in US Federal Safety Standards as the limiting value for head impact acceptability.

The computer analysis also showed that seat back breakover stiffness is critical in the control of occupant kinematics and should be controlled within close limits. This control should be part of a larger process to engineer seats to be more impact friendly in terms of both kinematics and attenuation, whilst avoiding sharp edges and protuberances.

2.6.3 Assessment of deceleration

There were 4 principal means of assessing the deceleration pulse transmitted, in the second impact, to the cabin floor around the centre-section. These were:

(i) KRASH simulation results
(ii) basic kinematics calculation
(iii) passenger and pilot seat damage related to dynamic testing
(iv) comparison with previous calibrated airframe tests.

It became evident during the survivability investigation that the major factor in determining the magnitude of the deceleration pulse in the second impact was the resultant (horizontal and vertical combined) velocity at this impact. The estimates basically covered the range of 77 knots to 99 knots: the highest probability was in the range of 85 to 95 knots.

On the balance of evidence, therefore, the KRASH simulation which best represented the velocity conditions at the second impact was Run 2 (Appendix 3, fig 22), which gave mid-fuselage longitudinal decelerations (mass 2) of 26.1 g (peak) and 17.8g (fundamental). Of these two values, the fundamental signal represented the plastic deformation signal transmitted to the seats and should be used for comparison purposes. The pulse shapes (appendix 3 fig 22) indicated that the initial impulse in the second impact was primarily longitudinal followed by a vertical pulse when the engine nacelles and the fuselage centre section contacted the carriageway. The corresponding value for the vertical deceleration was 23g (peak).

A basic kinematics calculation of the deceleration along the direction of motion, based on the measured crush distance and assuming a 25% velocity change in the second impact, gave a mean deceleration of about 22g.

The previous dynamic testing of Model 4001 passenger seats had shown deformation of the forward leg 'U-straps' in 16g longitudinal decelerations conducted with 170 lb dummies. (paragraph 1.6.8.3) The occurrence in ME of similar damage in centre-section seats with lighter occupant loadings indicated a resultant deceleration level in excess of this 16g level.

The 1988 FAA full-scale test of a complete section of B707 fuselage achieved a 14.2g longitudinal deceleration through a velocity change of 36.2 ft/sec with 6 triple-seats loaded, in each case, with three 165 lb dummies. The lack of failure or permanent deformation of the floor or of the seat tracks in that test indicated a longitudinal deceleration for ME well in excess of this 14.2g level.

In summary, these results indicated a resultant deceleration, in the second impact, within the centre section, with a peak value of between approximately 22 and 28g. The geometry of the impact showed that the initial pulse was primarily longitudinal, followed by a lower, vertical, pulse when the nacelles and centre section contacted the carriageway. The lack of damage in the tail section indicated a value there closer to, but still above, 14g. Previous, instrumented, impacts have indicated that the peak deceleration levels in the forward nose section would probably have been slightly higher than in the centre section.

2.6.4 *Seating*

From the analysis of the major deceleration impulse (paragraphs 1.16.4.2 & 2.6.3) it was apparent that the forces encountered in the second impact were considerably greater than those for which the airframe and the furnishings were designed and certificated. It is in this context that the discussion around the seat performance in ME takes place. Although the analysis of seat damage was complicated by the differing occupant weights and seat occupancy, a number of distinctive patterns emerged.

2.6.4.1 *Crew seating*

The injury scores of the cabin crew on the forward flight attendant seats were considerably lower than the passengers in the first rows of seats and this appears to have been due both to the fact that the attendant seats were rearward-facing and that the seats, although suffering some structural damage, remained in position. The advantages of the seating remaining in position and the provision of upper torso restraint are reinforced by the fact that the pilots, although seated in the area of highest deceleration, did not suffer injuries with scoring greater than the passengers in rows 1-5 (Area I in Appendix 3 fig 7). Both pilots' seats and the forward attendant seat suffered some structural damage. It is, however, not possible to tell whether this alleviated the impact loading or added to the occupant injuries.

The movement of the aft double attendant seat (paragraph 1.12.2.5) while still attached to its supporting bulkhead highlights the fact that a crew or passenger seat can only be as strong as the structure to which it is attached. Similarly, the injuries caused to the stewardess on this seat by a food service cart were due to the release of the cart by the upward structural separation of the counter-top on which the cart 'quarter-turn' latches were mounted and not by any seat failure.

2.6.4.2 *Passenger seating*

A distinctive feature of the reconstructed seats throughout the passenger cabin was that the rear attachments were generally still engaged with the seat track and that, where the seat and track had separated from each other, the absence of damage on the seat rear attachment fitting showed that it was the seat track which had failed. It appeared that the lack of structural failure in this area of the seats was at least partially due to the articulated joint built into the rear attachment (paragraph 1.6.8.3), an innovation largely stemming from the FAA dynamic test requirements (paragraph 1.17.11).

The front legs in this design of seat are not positively locked into the seat tracks and had thus become detached from the track lips in all areas where the continuity of the seat tracks was disrupted. In the centre and rear sections (Areas II and IV), where the seat track remained continuous, the front legs remained engaged and the number of 'U'-strap collapses was distinctly higher in the centre section (Area II) than in the areas forward and aft of the wing (Areas I and III). This confirmed that the disruption in the cabin floor in Areas I and III was largely due to the seat inertial loads passing through the front legs.

The examination of previous accidents (paragraph 1.17.17), the early dynamic testing of seats designed to the previous ('9g') static criteria and the dynamic testing of this model of passenger seat (paragraph 1.6.8.3) together indicated that fewer injuries occurred in ME than would probably have been the case with passenger seats of an earlier generation. However, some structural failures of the seats did occur, such as the front spar failures in the overwing section of the fuselage, and consideration should be given as to whether the new requirements of FAR Amendment 25-64 (paragraph 1.17.11), and hence JAR 25 Change 13, are sufficient in the long term.

The deceleration levels specified in the dynamic test requirements of FAR Amendment 25-64 (paragraph 1.17.11) were based on an FAA study of crash dynamics and were, to some extent, constrained by the need to be compatible with the existing floor strengths of current aircraft types and the existence of suitable test facilities. While the performance of the seats in ME indicates that seats designed to these dynamic requirements will certainly increase survivability in aircraft impacts, they do not necessarily represent an optimum for the long term. This is particularly true if matched with cabin floors of improved strength and toughness.

Another potential area for improvement is in the criteria applied to the loads experienced by the anthropomorphic dummy. For instance, the FAR Amendment

25-64 test measures femoral axial load without addressing the significant femoral bending loads.

It is recommended, therefore, that the CAA should actively seek further improvement in the standards of JAR 25.561 and .562 and the level of such standards should not be constrained by the current FAA requirements (Made 30 March 1990).

The provisions of Change 13 to JAR 25.561 and .562 are only applicable to new certifications and not to existing aircraft types nor their direct derivatives. Thus the fitting of the improved type of seats into ME was not a legal requirement. The performance of the passenger seats in ME, however, strongly supports the case for fitting the improved seats into the current fleet and into new aircraft of existing type. In the USA, for instance, NPRM 88-8 covers the proposed installation of the improved seats within the existing fleet by June 1995 (ie within about one 7-year replacement cycle).

It is recommended, therefore, that the CAA should require that, for aircraft passenger seats, the current loading and dynamic testing requirements of JAR 25.561 and .562 be applied to newly manufactured aircraft coming onto the UK register and, with the minimum of delay, to aircraft already on the UK register (Made 30 March 1990).

2.6.4.3 *Detail design of passenger seating*

Although few fatalities occurred in the centre and rear sections of the fuselage, the detailed injuries (paragraph 2.6.1) demonstrated the limitations of current seat designs. The high incidence of femoral and pelvic injuries coincided with the deformations of the horizontal spars and lower seat backs of the seats. Although these lower injuries were not fatal, they were generally serious and immobilizing and would have materially altered the outcome had there been a major ground fire.

The mechanisms of head and lower limb injuries identified by the medical investigation (paragraph 1.13) were consistent with the occupant simulation (paragraph 2.6.2).

The principle that careful detail design of the seats considerably affects the injury outcome of an accident also applies in the case of the injuries caused by passenger impacts with items such as seat-back tray tables and arm rests. The current airworthiness requirement addressing seat design, JAR 25.785, requires the 'elimination of any injurious object within the striking radius of the head' but does not apply any criteria defining sharpness or deformation under load and makes no requirements for parts of the body other than the head. It also does not specify parameters such as seat back stiffness, which the occupant simulation identifies as being critical in the control of the kinematics of the occupant, or seatbelt webbing stiffness which can also greatly affect the kinematics. It is recommended, therefore, that in addition to the dynamic test requirements, the CAA should seek to modify the JARs associated with detailed seat design to ensure that such seats are safety-engineered to minimise occupant injury in an impact (Made 30 March 1990).

2.6.5 *Alternative seating configurations*

Throughout the development of public transport aircraft there have been a number of alternative seating configurations proposed, including energy-absorbing 'stroking' seats, three point harnesses and rearward facing seats. Each offers some advantage in passenger impact protection but also presents technical problems which need to be addressed. In the case of the energy-absorbing seat, for instance, the inertial loads on the passenger and the supporting structure would be relieved. A potential disadvantage would be the trapping of the legs of passengers in the adjacent row.

The attachment of a three point harness with lap and diagonal straps, such as commonly seen in automobiles, would require either a redesign of the seat back so that shoulder harness loads could be reacted, or that the shoulder harness be attached to the fuselage itself. This latter proposition is probably only applicable to commuter type aircraft. The harness would need to be on an inertial reel to avoid problems of harness entanglement on escape. Such a harness would produce a reduction in the degree of head and chest injury and would also have a significant effect on leg and pelvic injury because of improved kinematics and better load distribution. Appendix 5, fig 5 shows a further MADYMO graphic using the Cranfield Impact Centre KRASH data. A three point harness with the upper attachment made to the fuselage is shown. Comparison with Appendix 5, fig 4 shows the considerable improvement in occupant kinematics that is achieved.

An objection to using the three point harness is the effect that it would have on movement over the seats as an alternative form of exit in an emergency. Clearly, if the harness were to be attached to the top of the seat, the seat back would have to be made rigid and it would no longer be possible to collapse the seat back forward. Where a shoulder harness was attached to the airframe the option would still be lost, since a considerable potential for entanglement would exist.

An alternative to the three point harness is the rearward facing seat. Such a seat would be specifically designed for this configuration and the impact loads, instead of being carried on the lap belt and by contact of unrestrained body segments with the seat in front, would be evenly distributed across the seat back. The result, in this accident, given similarly strong seats that remained attached to the floor, would have been a considerable reduction in the severity of impact injury. Use of the rearward facing seat would be open to a number of practical difficulties. Static calculation indicates that the loads that such a seat would impart to the cabin floor, on impact, would be greater than with a forward facing seat. This is because the rearward facing seat back generates a greater moment-arm on the floor than is the case for the forward facing seat. Advice from the seat manufacturers and the Civil Aeromedical Institute of the FAA (paragraph 1.17.13) indicated that the difference dynamically is not as great as the static calculation suggests. This observation was born out by the MADYMO load simulations (see Appendix 5, fig 6). In this simulation the simulated seat has been stiffened and the pulse reversed. The seat back height has not been increased, which would be required to protect the neck. The incorporation of a limited amount of energy attenuation in the seat struts could reduce the loads into the cabin floor to those of standard forward facing seats.

A further objection raised against rearward facing seats is that the seat occupant would be exposed to facial impact from loose objects liberated during the impact. This is theoretically true but the solution seems to lie with achieving retention of overhead bins and their contents rather than avoiding the use of rearward seats. It is also likely that the incorporation of a three point harness on a forward facing seat would expose the occupant to a greater risk of head impact from behind for the same reasons, as the head would be maintained in a more erect posture. Clearly the solution to this problem must lie in the avoidance of free flying objects, rather than the rejection of improved occupant restraint.

Common to all the alternative seating configurations proposed is that they have complex implications and implementation would have to be founded on a firm basis of research and development. This would have to include such questions as the compatibility with the rest of the cabin, the level of passenger acceptability and the ability of the configuration to provide protection in a wide range of impact conditions. Up to now little of this research has taken place and the limited use of rearward facing seats in military transport aircraft has not answered these questions. It is, therefore, recommended that the CAA should initiate and expedite a structured programme of research, in conjunction with the European airworthiness authorities, into passenger seat design, with particular emphasis on:

(i) Effective upper torso restraint.

(ii) Aft-facing passenger seats (Made 30 March 1990).

2.6.6 *Cabin floor structure*

The study of a sample of narrow-body jet transport accidents (paragraph 1.17.17) showed that the impact and structural disruption to ME was reasonably characteristic of off-airfield accidents involving landing undershoots, failed go-arounds and power-off forced landings, because although the geometry of the major impact was severe, it occurred at a speed below the stalling speed of the aircraft. The deceleration impulses (paragraph 2.6.3) were within the tolerance of a typical passenger when properly restrained. The preceding analysis of the seating in ME illustrates that the passenger seats remained in position in the areas in which the floor structure had survived intact. It was in the areas in which the floor had disintegrated that the most severe injuries occurred (paragraph 2.6.1).

A distinctive pattern of failure emerged from the examination of the floor structure (paragraph 1.12.2.7). The initial failure was of the longitudinal seat tracks under the vertical and longitudinal impact loading of the passenger triple-seats. The resulting displacement of the seat track members from the floor panels prevented those floor panels from reacting the longitudinal crash loads. The transverse floor beams then failed under the longitudinal and torsional crash loads, for which they were not designed, as well as from the vertical crash loads.

The floor structure in ME was typical of this class of aircraft. The certification data for this aircraft showed that the floor structure met the airworthiness strength requirements both of the USA and the UK. The impact of ME clearly exceeded these requirements (paragraphs 1.16.4.2 & 2.6.3). These requirements were current at the time of the granting of the type certificate to the Boeing 737-100 in 1967. They were for static strength only and did not require the manufacturer to demonstrate crashworthiness characteristics, beyond those static strength requirements.

A part of the rationale for the dynamic test requirements, such as the 16g/44fps longitudinal deceleration, selected by the FAA in the FAR Part 25 rule change (Amendment 25-64) was that these requirements were compatible with existing cabin floor strengths (paragraph 1.17.11). This has been largely supported by crash dynamics research, including large-scale dynamic testing (paragraph 1.17.12). However, the overall pattern of failure in ME, particularly regarding the lack of plastic deformation, showed that relatively minor engineering changes could significantly improve the resilience and toughness of cabin floors in this category of aircraft and take fuller advantage of the improved passenger seats. In particular, there would appear to be benefit in improved tolerance to out-of-plane loading and the provision of multiple load paths.

Although it may be questionable whether the cost and benefit balance would favour modification of existing airframes, future designs should certainly take account of dynamic loading criteria. This principle should also apply to future production of existing designs of transport aircraft. It is recommended, therefore, that the certification requirements for cabin floors for new aircraft types should be modified to require that dynamic impulse and distortion be taken into account and these criteria should be applied to future production of existing designs (Made 30 March 1990).

2.6.7 *Future floor requirements*

Looking towards future designs of cabin floor, it should be considered whether a substantial increase in decelerative loading could be accomplished, so as to take advantage both of seats designed to meet the current dynamic test requirements and future seats with enhanced capabilities.

The customary argument against large increases in cabin furnishing strength has been that such increases would require uneconomic weight increases in the fuselage to maintain the protection of the fuselage shell. However, the case of the L-1011 Tristar accident in the Everglades (paragraph 1.17.17) suggests that, even with very extensive fuselage disruption, a reduced number of fatalities and serious injuries will result from retaining the passenger seats on areas of toughened flooring so that, even after detachment from the fuselage shell, the seats will remain attached and retain their relative position on the flooring. It is recommended, therefore, that the CAA should initiate research, in conjunction with the European airworthiness authorities, into the feasibility of a significant increase in cabin floor toughness beyond the level of the current JAR/FAR seat requirements (Made 30 March 1990).

2.6.8 *Infant and child restraint systems*

The argument for child seats in cars has been well-established for over a decade. That an equivalent argument for placing infants and young children in child seats in aircraft has not emerged is at least partly due to the statistically small population of infants travelling by air and the failure of airline passenger statistics to reflect their presence.

It is clear from paragraph 1.17.14 that the supplementary loop-type belt provides some advantages over simple lap-holding of infants. It cannot provide, however, an equivalent level of survivability to that provided for the adult passenger in a conventional seat, or the greater level of survivability provided by a '16g' type passenger seat. It is recommended therefore that the CAA implement a programme to require that all infants and young children, who would not be safely restrained by supplementary or standard lap belts, be placed in child seats for take-off, landing and flight in turbulence (Made 30 March 1990).

In this light, the CAA Notice (paragraph 1.17.14) allowing the use of specific types of child seat should be welcomed. In general, the provisions of the notice align it with current FAA practice. This FAA practice reflects its origins in US general aviation and has clear limitations as a means of bringing about the universal use of child seats in transport aircraft. For instance, a passenger may unintentionally provide a non-approved child seat, or one incompatible with that airline's seat width and, even if the child seat is suitable, there is no compulsion on the airline to allow its use.

As a means of bringing about the universal use of child seats, therefore, it is logical that the onus of provision should be placed on the airline operator. There are clear advantages for an airline in only having to train its cabin staff to deal with the use of one type of child seat, optimised for the airline operation, and there are clear advantages for the passenger in not having to provide such a seat.

In the meantime, to promote the effective use of child seats and to put operators in a position to provide child seats themselves, a UK or JAA standard should be rapidly established for child seats for use in aircraft. It is therefore recommended *that the CAA expedite the publication of a specification for child seat designs* (Made 30 March 1990).

2.6.9 Overhead stowage bins

A notable feature of the aircraft wreckage was that all but one of the overhead stowage bins had become detached in the impact and that they had done so in a very similar manner (paragraph 1.12.2.8). In this mode of failure the first stage was the separation of the diagonal tie fitting from the upper surface of the stowage bin under the influence of the predominantly longitudinal inertial loads in the second impact. This was followed by the failure of the remaining lateral and vertical ties when the bins moved forward (Appendix 3, fig 21).

Confirmation of this failure mode was that the only bin not to have separated entirely from its fuselage attachments was 1R, the only bin at which forward motion was restricted by the presence of a substantial cabin bulkhead.

Although it was not possible to determine the actual mass or distribution of passenger belongings in the overhead bins, the results of the 1981-82 CAA survey (paragraph 1.17.15) indicated that the manufacturer's design and certification figure (3 lbs per inch of bin length) was generously conservative. In normal operation, it is unlikely that a set of bins would be overloaded.

As Flight BD092 was normally a routine and conventional operation, the assumed mass of passenger belongings (33% of placarded mass - paragraph 1.17.15) is probably reasonably accurate and there is no reason to believe that the static load testing performed for the FAA, and the static load analysis calculated for the CAA's more stringent requirements, were flawed. It is not, therefore, obvious why the bin attachments failed so consistently.

One possibility considered was that the product of the bin masses and their deceleration was sufficient to induce higher loads than the design and certification limitations of the attachments. Depending upon the exact figures used, this argument can be supported for the nose and centre sections of the fuselage, but the deceleration pulse in the tail section indicated by the KRASH analysis, by the seat and track damage and by the occupant injuries, was probably too low in the tail section for the impact loads to have been the only cause of the attachment failures.

This leads to the conclusion that the design of the overhead stowage bins installed in ME was not sufficiently robust to withstand the deformation of the attachment structure combined with the dynamic loading of the second impact. This dynamic loading ensured that, as well as the geometry of the fuselage attachments being deformed, the failure of one bin's longitudinal restraint would have resulted in additional loading on the ties of neighbouring bins, resulting in a cascading sequential failure.

Although the injury evidence (paragraph 1.13) did not indicate the degree of injury attributable to the bins, it is evident that they can cause additional injuries as well as hampering escape and rescue. In this accident, the almost complete detachment of the bins slowed down the rescue process and, had the ground fire spread, the result would have been more serious.

The current design load requirements for 'items of mass' in the cabin (paragraph 1.17.11) were derived from loadings under which the fuselage would remain structurally intact. Whatever the historical justification for this, ME and other accidents to modern narrow-body jet transports (paragraph 1.17.17) indicate that there is considerable benefit in retaining these items of mass in position despite the deformation of the fuselage attachment structure and even after some disruption of the fuselage. Such items of mass include cabin equipment (eg food service carts) as well as fixed items such as overhead bins and toilet modules. This improvement in retention would require both a substantial increase in the appropriate design load factors and design features (such as the incorporation of flexible mountings) to ensure that the items of mass would be restrained against the dynamic application of the crash pulses which generate these load factors.

It is recommended, therefore, that the certification requirements for cabin stowage bins, and other cabin items of mass, should be modified to ensure the retention of these items to fuselage structure when subjected to dynamic crash pulses substantially beyond the static load factors currently required (Made 30 March 1990).

There was also evidence that some of the bin doors opened during the last moments of flight, before the first impact (paragraph 1.15.1). The inadvertent opening of overhead stowage bins has long been a problem, especially in turbulence, and some airlines now fit bins which incorporate some form of secondary latching. It is recommended, therefore, that the CAA consider improving the airworthiness requirements for public transport aircraft to require some form of improved latching to be fitted to overhead stowage bins and this should also apply to new stowage bins fitted to existing aircraft (Made 30 March 1990).

3. CONCLUSIONS

(a) Findings

The aircraft

1 The aircraft had a valid certificate of airworthiness in the transport category (passenger) and had been maintained in accordance with an approved schedule.

The flight deck crew

2. The flight deck crew were properly licensed and rested to undertake the flight.

3. The flight deck crew experienced moderate to severe engine induced vibration and shuddering, accompanied by smoke and/or smell of fire, as the aircraft climbed through FL283. This combination of symptoms was outside their training or experience and they responded urgently by disengaging the autothrottles and throttling-back the No 2 engine, which was running satisfactorily.

4. After the autothrottle was disengaged, and whilst the No 2 engine was running down, the No 1 engine recovered from the compressor stalls and began to settle at a slightly lower

fan speed. This reduced the shuddering apparent on the flight deck, convincing the commander that they had correctly identified the No 2 engine as the source of the problem.

5. The first officer reported the emergency to ATC, indicating that they had an engine fire and intended to shut an engine down, although there had been no fire warning from the engine fire detection system.

6. Whilst the commander's decision to divert to East Midlands Airport to land with the minimum of delay was correct, he thereby incurred a high cockpit workload which precluded any effective review of the emergency or the actions he had taken.

7. The flight crew did not assimilate the readings on the engine instruments before they decided to throttle-back the No 2 engine. After throttling back the No 2 engine, they did not assimilate the maximum vibration indication apparent on the No 1 engine before they shut down the No 2 engine 2 minutes 7 seconds after the onset of vibration, and 5 nm south of EMA. The aircraft checklist gave separate drills for high vibration and for smoke, but contained no drill for a combination of both.

8. The commander remained unaware of the blue sparks and flames which had issued from the No 1 engine during the period of heavy vibration and which had been observed by many passengers and the three aft cabin crew.

9. During the descent, the No 1 engine continued to run apparently normally, although with higher than normal levels of vibration.

10. Flight crew workload during the descent remained high as they informed their company at EMA of their problem and intentions, responded to ATC height and heading instructions, obtained weather information for EMA and the first officer attempted to re-programme the flight management system to display the landing pattern for EMA. Some 7½ minutes after the initial problem, the commander attempted to review the initial engine symptoms, but this was cut short by further ATC heading and descent information and instructions to change to the EMA ATC radio frequency.

11. Fifteen minutes after the engine problem occurred and some 4 minutes 40 seconds before ground impact, the commander increased power on the No 1 engine as the aircraft descended towards 3000 feet amsl and closed with the centreline of the instrument landing system. At this point, the indicated vibration on the No 1 engine again rose to its maximum value of 5 units but did not attract the attention of either pilot.

12. Fifty three seconds before ground impact, when the aircraft was 900 feet agl and 2.4 nm from the runway with landing gear down and 15° flaps selected, there was an abrupt decrease in power from the No 1 engine.

13. The commander immediately called for the first officer to relight the No 2 engine. The attempted restart was not successful, probably because there was insufficient bleed air pressure from the No 1 engine, pressure air from the APU was not connected and the bleed air crossfeed valve was closed. Even if pressure air had been available it is unlikely that power could have been obtained from the No 2 engine before the aircraft hit the ground.

14. The training of the pilots met CAA requirements. However, no flight simulator training had been given, or had been required, on the recognition of engine failure on the electronic engine instrument system or on decision-making techniques in the event of failures not covered by standard procedures.

15. The change from hybrid electro-mechanical instruments to LED displays for engine indications has reduced conspicuity, particularly in respect of the engine vibration indicators. No additional vibration alerting system was fitted that could have highlighted to the pilots which of the two engines was vibrating excessively.

The Cabin Crew

16. All members of the cabin crew were properly trained to undertake the flight.

17. Although the cabin crew immediately became aware of heavy vibration at the onset of the emergency and three aft cabin crew saw flames emanating from the No 1 engine, this information was not communicated to the pilots.

18. During the descent, the cabin crew carried out their emergency drills, checking that all passengers had their lap belts fastened and stowing all loose carry-on luggage in the overhead bins.

No 1 (Left) Engine

19. The No 1 engine suffered fatigue of one of its fan blades which caused detachment of the blade outer panel. This led to a series of compressor stalls, over a period of 22 seconds, until the engine autothrottle was disengaged.

20 The severe mechanical imbalance which arose because of the outer panel separation led to blade tip rubbing, particularly on the fan and booster sections abradable seals, which caused smoke and the smell of burning to be passed into the air conditioning system.

21. About 3 seconds after the autothrottle was disengaged, and whilst the No 2 engine was running down, the No 1 engine began to stabilise. However, its indicated vibration remained at maximum for at least 3 minutes until this engine was throttled back for the descent.

22. The evidence indicated that the timing of the sudden recovery of the No 1 engine from the compressor stalling was related to the autothrottle disengagement at a point when it had demanded a lower throttle lever angle than that required for rated climb, thereby allowing this engine to achieve stabilised running at a slightly lower speed.

23. During the descent, the No 1 engine responded apparently normally at the idle/low throttle settings used, although its indicated vibration remained higher than normal.

24. Fifty three seconds before ground impact, the No 1 engine abruptly lost thrust as a result of extensive secondary fan damage. This was accompanied by compressor stalling, heavy buffetting and the emission of pulsating flames. This damage was probably initiated by fan ingestion of the blade section released by the initial failure, which was considered to have partially penetrated, and temporarily lodged within, the acoustic lining panels of the intake casing before having been shaken-free during the period of high vibration following the increase in power on the final approach to land. Sections of fan blades were found below this point of the final approach, including two small fragments which were determined to be remnants of the blade section which detached initially.

25. The No 1 engine fire warning, which occurred on the flight deck 36 seconds before ground impact, was initiated by a secondary fire which occurred on the outboard exterior of the engine fan casing. It was concluded that the prolonged period of running under conditions of excessive vibration had loosened fuel/oil system unions and seals on the exterior of the fan casing and that the inlet duct had probably been damaged sufficiently, by fan blade debris, to allow ignition of atomised fuel/oil sprays by titanium 'sparks' and/or intake flame.

26. This short duration in-flight fire on the No 1 engine was followed by a localised ground fire associated with this engine, which was successfully extinguished by the East Midland Airport Fire Service.

27. The fan blade fatigue fracture initiated as a result of exposure of the blade to a vibratory stress level greater than that for which it was designed, due to the existence of a fan system vibratory mode, induced under conditions of high corrected fan speed at altitude, which was not detected by engine certification testing.

No 2 (right) engine

28. The No 2 engine was running normally when it was throttled back to flight idle, and then shut down.

29. This engine showed no evidence of power at impact, consistent with the evidence from the flight data recorder.

30. Detailed strip inspection of this engine showed it to have been fully serviceable before ground impact.

Systems

31. The No 2 (right) engine vibration reports which appeared in the aircraft Technical Log during December 1988 but had been correctly addressed by ground technicians.

32. There were no malfunctions of the major airframe systems which contributed to this accident.

33. No evidence was found of any cross-connection or similar obvious wiring errors associated with either the engine instrument system (EIS) or the fire detection system.

34. The EIS fitted to the aircraft was serviceable at impact and tests indicated that it should have displayed those primary engine parameters recorded on the FDR, with close fidelity.

35. The airborne vibration monitoring system (AVM) was serviceable at impact. Tests showed that the system was capable of tracking vibration caused by the massive fan imbalance and of outputting its maximum value approximately 2 seconds after the start of the vibration.

36. Flight crew reports concerning the response of the AVM system during the two other cases of fan blade fracture on CFM56-3C engines which occurred subsequent to this accident supported the behaviour described above. Two cases of bird impact which resulted in fan damage generated crew reports of late indication on vibration gauges, although vibration was clearly felt by the flight crew. This was the result of the non-linear sensitivity of this engine type to small imbalances with changes of fan speed in the take-off and climb thrust range.

37. The engine fire and overheat detection system contained a fault which could have rendered it incapable of providing warning of a fire in either engine. However, the CVR evidence indicated that it did, in fact, provide a warning of the fire in the No 1 engine 36 seconds before impact.

Impact with the ground

38. The aircraft suffered two distinct impacts with the ground, the first just before the eastern embankment of the M1 motorway and the second on the western edge of the northbound M1 carriageway, at the base of the western embankment.

39. The first impact was at an airspeed of 113 knots CAS, with a rate of descent of between 8.5 feet/sec and 16 feet/sec. The pitch attitude was 13° nose up.

40. The second and major impact occurred at a speed of between 80 and 100 knots, at an angle of approximately 16° below the horizontal and with the aircraft at a pitch attitude of between 9° and 14° nose down. The associated peak deceleration was of the order of 22 to 28g, predominantly longitudinal.

41. In the second impact the forward fuselage separated from the overwing section of fuselage and the tail section buckled over, and to the right of, that section of fuselage just aft of the wing.

42. The incidence of passenger fatality was highest where the floor had collapsed in the forward section of the passenger cabin and in the area just aft of the wing. The cabin floor and the passenger seating remained almost entirely intact within the overwing and tail sections.

43. There was no major post impact fire, largely because the main landing gear legs and the engines separated from the wing without rupturing the wing fuel tanks. The separation of the landing gear legs was in accordance with their design. In the case of the engines, however, the separations occurred within the engine pylons themselves, leaving the fuse-pin bolts intact

Survivability

44. Of the 8 crew and 118 passengers on board, all crew members survived but 39 passengers died from impact injuries at the scene and a further 8 passengers died later in hospital. A further 74 occupants were seriously injured.

45. The decelerations generated in the second impact were greater than those specified in the Airworthiness Requirements to which the airframe and furnishings were designed and certificated. They were, however, within the physiological tolerance of a typical passenger.

46. Passenger survivability was improved due to the passenger seats being of a design with impact tolerance in advance of the current regulatory requirements. This was most evident in the overwing and tail sections of the cabin, where the floor had remained intact.

47. There is considerable potential for improving the survivability of passengers in this type of impact by improving the structural integrity of the cabin floor so as to retain the seats in their relative positions and by detail design improvements to the seats themselves.

48. There is a need for a structured programme of research into alternative seating configurations, with particular emphasis on the provision of effective upper torso restraint or aft-facing seats.

49. The injuries to the mother and child in seat 3F highlighted the advantages of infants being placed in child seats rather than in a loop-type supplementary belt.

50. Although the overhead stowage bins met the appropriate Airworthiness Requirements for static loading, all but one of the 30 bins fell from their attachments, which did not withstand the dynamic loading conditions in this accident.

51. Some of the doors on the overhead stowage bins opened during the last seconds of flight, demonstrating the need for some form of improved latching of the doors.

(b) Cause

The cause of the accident was that the operating crew shut down the No 2 engine after a fan blade had fractured in the No 1 engine. This engine subsequently suffered a major thrust loss due to secondary fan damage after power had been increased during the final approach to land.

The following factors contributed to the incorrect response of the flight crew:

1. The combination of heavy engine vibration, noise, shuddering and an associated smell of fire were outside their training and experience.

2. They reacted to the initial engine problem prematurely and in a way that was contrary to their training.

3. They did not assimilate the indications on the engine instrument display before they throttled back the No 2 engine.

4. As the No 2 engine was throttled back, the noise and shuddering associated with the surging of the No 1 engine ceased, persuading them that they had correctly identified the defective engine.

5. They were not informed of the flames which had emanated from the No 1 engine and which had been observed by many on board, including 3 cabin attendants in the aft cabin.

4. Safety recommendations

The following safety recommendations were made during the course of the investigation.

4.1 That the CAA consider increasing the frequency of existing engine inspections and engine health monitoring on Boeing 737-300 and Boeing 737-400 aircraft until the causes of the engine failure(s) are established. (Precautionary Recommendation made 11 January 1989.)

4.2 That the CAA call for an examination of the Boeing 737-300 and Boeing 737-400 engine Fire/Overheat and Vibration monitoring circuitry for left/right engine sense. (Precautionary Recommendation made 11 January 1989.)

4.3 The Civil Aviation Authority, in conjunction with the engine manufacturer, consider instituting inspection procedures for the examination of the fan stage of CFM56 engines to ensure the early detection of damage that could lead to the failure of a blade. (Made 10 February 1989)

4.4 The Civil Aviation Authority review the advice given in the Boeing 737-400 Maintenance Manual concerning the excessive generation of heat during blending operations with power grinding and blending tools. (Made 10 February 1989)

4.5 The CAA should take action to advise pilots of Boeing 737-300/400 aircraft, and of other types with engines which have similar characteristics, that where instances of engine-induced high vibration occur, they may be accompanied by associated smoke and /or smells of burning entering the flight deck and/or cabin through the air-conditioning system, due merely to blade tip contact between fan/compressor rotating assemblies and the associated abradable seals. (Made 23 February 1989)

4.6 The CAA should review the current attitude of pilots to the engine vibration indicators on Boeing 737-300/400 aircraft, and other applicable types with turbofan engines, with a view towards providing flight crews with an indication of the pertinence of such vibration instruments when engine malfunctions or failures occur. (Made 23 February 1989)

4.7 The CAA should require that pilot training associated with aircraft which are equipped with modern vibration systems[7], and particularly those aircraft which are fitted with high by-pass turbofan engines, should include specific instruction on the potential value of engine vibration indicators in assisting the identification of an engine which has suffered a failure associated with its rotating assemblies. (Made 30 March 1990)

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[7] Excluding those aircraft fitted with a computerised engine warning system which includes engine vibration as an alerting parameter.

4.8 The regulatory requirements concerning the certification of new instrument presentations should be amended to include a standardized method of assessing the effectiveness of such displays in transmitting the associated information to flight crew, under normal and abnormal parameter conditions. In addition, line pilots should be used in such evaluations. (Made 30 March 1990)

4.9 The CAA should require that the engine instrument system on the Boeing 737-400, and other applicable public transport aircraft, be modified to include an attention-getting facility to draw attention to each vibration indicator when it indicates maximum vibration. (Made 30 March 1990)

4.10 The CAA should request the Boeing Commercial Airplane Company to produce amendments to the existing aircraft Flight Manuals to indicate what actions should be taken when engine-induced high vibration occurs, accompanied by smoke and/or the smell of burning entering the flight deck and/or cabin. (Made 23 February 1989)

4.11 The CAA should ensure that flight crew currency training in simulators includes practice reprogramming of flight management systems, or any other such systems which control key approach and landing display format, during unplanned diversions so that they remain practised in the expeditious use of such systems. (Made 30 March 1990).

4.12 The CAA should review the current guidance to air traffic controllers on the subject of offering a discrete RT frequency to the commander of a public transport aircraft in an emergency situation, with a view towards the merits of positively offering this important option. (Made 30 March 1990).

4.13 The CAA should review current airline transport pilot training requirements to ensure that pilots, who lack experience of electronic flight displays, are provided with familiarisation of such displays in a flight simulator, before flying public transport aircraft that are so equipped. (Made 30 March 1990).

4.14 Training exercises for pilots and cabin crew should be introduced to improve co-ordination between technical and cabin crews in response to an emergency. (Made 30 March 1990).

4.15 The CAA should review current airline transport pilot training requirements with a view towards considering the need to restore the balance in flight crew technical appreciation of aircraft systems, including systems response under abnormal conditions, and to evaluate the potential of additional simulator training in flight deck decision making. (Made 30 March 1990).

4.16 The type certification requirements for gas turbine engines should be amended so that it is mandatory to perform instrumented flight tests to demonstrate freedom from damaging vibratory stresses at all altitude conditions and powers which an engine will encounter in service (Made 30 March 1990).

4.17 The potential for fuel and oil system leakage within the fan case area of high by-pass turbofan engines, during conditions of excessive vibration, should be reviewed by the engine manufacturers and the CAA with a view towards modifying such systems to minimise such leakage, and the associated fire risk (Made 30 March 1990).

4.18 The CAA should review the existing Joint Airworthiness Requirements concerning fuel tank protection from the effects of main landing gear and engine detachment during ground impact and include specific design requirements to protect the fuel tank integrity of those designs of aircraft with wing-mounted engines (Made 30 March 1990).

4.19 The CAA should expedite current research into methods of providing flight deck crews of public transport aircraft with visual information on the status of their aircraft by means of external and internal closed circuit television monitoring and the recording/recall of such monitoring, including that associated with flight deck presentations, with a view towards producing a requirement for all UK public transport aircraft to be so equipped (Made 30 March 1990).

4.20 The manufacturers of existing flight data recorders which use buffering techniques should give consideration to making the buffers non-volatile and hence recoverable after loss of power, and EUROCAE and the CAA should reconsider the concept of allowing volatile memory buffering in flight data recorders (Made 30 March 1990).

4.21 Where engine vibration is an available parameter for flight data recording, the CAA should consider making a requirement for it to be recorded at a sampling rate of once every second (Made 30 March 1990).

4.22 The CAA should actively seek further improvement in the standards of JAR 25.561/.562 and the level of such standards should not be constrained by the current FAA requirements (Made 30 March 1990).

4.23 The CAA should require that, for aircraft passenger seats, the current loading and dynamic testing requirements of JAR 25.561 and .562 be applied to newly manufactured aircraft coming onto the UK register and, with the minimum of delay, to aircraft already on the UK register (Made 30 March 1990).

4.24 In addition to the dynamic test requirements, the CAA should seek to modify the JARs associated with detailed seat design to ensure that such seats are safety-engineered to minimise occupant injury in an impact (Made 30 March 1990).

4.25 The CAA should initiate and expedite a structured programme of research, in conjunction with the European airworthiness authorities, into passenger seat design, with particular emphasis on:

(i) Effective upper torso restraint.
(ii) Aft-facing passenger seats. (Made 30 March 1990)

4.26 The certification requirements for cabin floors of new aircraft types should be modified to require that dynamic impulse and distortion be taken into account and these criteria should be applied to future production of existing designs (Made 30 March 1990).

4.27 The CAA should initiate research, in conjunction with the European airworthiness authorities, into the feasibility of a significant increase in cabin floor toughness beyond the level of the current JAR/FAR seat requirements (Made 30 March 1990).

4.28 The CAA implement a programme to require that all infants and young children, who would not be safely restrained by supplementary or standard lap belts, be placed in child-seats for take-off, landing and flight in turbulence (Made 30 March 1990, amended 8 August 1990).

4.29 The CAA expedite the publication of a specification for child seat designs (Made 30 March 1990).

4.30 The certification requirements for cabin stowage bins, and other cabin items of mass, should be modified to ensure the retention of these items to fuselage structure when subjected to dynamic crash pulses substantially beyond the static load factors currently required (Made 30 March 1990).

4.31 The CAA consider improving the airworthiness requirements for public transport aircraft to require some form of improved latching to be fitted to overhead stowage bins and this should also apply to new stowage bins fitted to existing aircraft. (Made 30 March 1990)

ICAO Note.— Sections 1.5.3, 1.6.2 to 1.6.10, 1.12, 1.16, 1.17, and the Appendices were not reproduced.

ICAO Ref.: 003/89

No. 2

Boeing 707-300, accident at Santa Maria, the Azores, Portugal on 8 February 1989. Aircraft Accident Report DGAC/GPI/RA – 89/05 released by Direcção – Geral da Aviação Civil, Portugal

SYNOPSIS

Date of accident	:	8 February 1989 at 1408:12 UTC
Place of accident	:	Pico Alto, Santa Maria, Azores Latitude: 36°58'48''N Longitude: 36°05'28''W Altitude: 1795 ft (547 m)
Nature of flight	:	Charter flight, non-scheduled transport of passengers
Flight number	:	IDN 1851
Aircraft	:	BOEING 707-331B Serial No. 19572 Nationality and registration marks: N7231T
Owner	:	IAL Services, Inc.
Operator	:	Independent Air, Inc.
Persons on board	:	Flight crew - 3 Cabin crew - 4 Passengers - 137
Consequences	:	144 dead Aircraft destroyed Forest partially destroyed

SUMMARY OF ACCIDENT

The aircraft was on a non-scheduled flight from Bergamo, Italy to Santa Maria, Azores, where it was to make a technical stop after which it would go on to Punta Cana, Dominican Republic. Before initiating the descent to Santa Maria Airport, the pilots received the current meteorological information, with a QNH of 1 019 hPa.

Twelve minutes and twenty-eight seconds later, while still in the descent phase, they were cleared by Approach Control to descend to an altitude of 3 000 ft (the minimum safety altitude for the sector), with a QNH of 1 027 hPa, 9 hPa higher than the actual value; the co-pilot understood this altitude as 2 000 ft. Because of an overlap of communications between the aircraft and the Tower, the latter could not become aware of the crew's mistake.

At 1408:12 UTC, the aircraft crashed into Pico Alto, at an altitude of 1 795 ft (547 m).

It is concluded that the accident was probably caused by the fact that the crew deliberately descended to 2 000 ft, i.e. 1 000 ft below the minimum sector altitude, which was published on the aeronautical charts and transmitted to the crew by Santa Maria Approach Control.

1.0 FACTUAL INFORMATION

1.1 History of the flight

1.1.1 The flight

The aircraft was on a non-scheduled public transport flight from Bergamo, Italy to Santa Maria, Azores, where it was to make a technical stop after which it would go on to Punta Cana, Dominican Republic.

The aircraft refuelled at Bergamo and it was determined that the amount of fuel on board had been correctly worked out for the flight. There was enough fuel for destination, alternate, holding, reserve and stop, for a total of 68 000 lb (30 844 kg).

Flight number IDN 1851, which was due to leave at 0800 UTC on 8 February 1989, took off from Bergamo at 1004 UTC because the previous flight had arrived late. ETA at Santa Maria was 1405 UTC, using the computerized flight plan prepared by Lockheed (LOCKHEED DATA PLANE REPORT No. 1406).

The flight progressed normally and in accordance with the above-mentioned flight plan (Annex 1).

At 1246:33 UTC, the Santa Maria Area Control Centre, Oceanic Sector, gave IDN 1851 an oceanic clearance for the flight to proceed via MAKIN to ECHO and SMA:

"SANTA MARIA OCEANIC CLEAR IDN 1851 TO PROCEED VIA MAKIN THREE EIGHT NORTH TWO ZERO WEST ECHO SIERRA MIKE ALPHA FLIGHT LEVEL THREE FIVE ZERO MACH DECIMAL EIGHT ZERO READ BACK READ BACK"

At 1344:20 UTC, at the request of IDN 1851, Santa Maria Approach Control transmitted the latest METAR, ending with the information that the QNH was 1 019 hPa.

At 1348:16 UTC, IDN 1851 requested clearance from the Santa Maria Area Control Centre, TMA position (frequency of 132.15 MHz) to initiate descent, and was cleared to descend to flight level 40.

During this flight stage and after the crew was cleared to initiate descent, there was no indication that the flight engineer had read out any checklist whatsoever. Nor was the above-mentioned descent clearance repeated aloud by the captain to the other two flight crew members.

At 1355:53 UTC, at the request of Santa Maria Approach Control, IDN 1851 reported passing through FL 220.

At 1355:57 UTC, Santa Maria Approach Control asked IDN 1851 to report when overhead of ECHO, which was done 18 seconds later.

At 1356:23 UTC, the Santa Maria Area Control Centre, TMA position, instructed IDN 1851 to transfer communications to the Aerodrome Control Tower on 118.1 MHz.

At 1356:47 UTC, Santa Maria Tower cleared IDN 1851 to descend to 3 000 ft on a QNH of 1 027 hPa, in order to make an ILS approach to runway 19, with the following message: **"INDEPENDENT AIR ONE EIGHT FIVE ONE ROGER RECLEAR TO THREE THOUSAND FEET ON QNH ONE ZERO TWO SEVEN AND RUNWAY WILL BE ONE NINER"**; there was a brief pause, and at 1356:59 UTC, the message resumed as follows: **"EXPECT ILS APPROACH RUNWAY ONE NINER REPORT REACHING THREE THOUSAND"**.

At the same time, at 1356:59 UTC, IDN 1851 sent the following message to Santa Maria Tower:

"RECLEAR TO TWO THOUSAND FEET AND AH...", which after a pause continued as follows at 1357:07 UTC: **"ONE ZERO TWO SEVEN"**.

Immediately after the first part of this last message, one of the other two flight crew members, who could not be identified, called the co-pilot's attention in order to correct to 3 000 ft. The co-pilot interrupted the message, keeping his finger on the PTT button, which he released momentarily then pressed again, resuming the communication without making any correction. After this communication of the QNH value, it was questioned by the co-pilot himself, who said **"is that what he said ten twenty-seven on the millibars"**, which the captain confirmed.

Meanwhile, one of the pilots entered into the "Altitude Alert" the altitude of 2 000 ft and the QNH of 1 027 hPa.

Shortly thereafter, the flight engineer started reading out the "Landing Preliminary Checklist". With regard to the "Altimeter" item, both pilots answered "set and crosschecked", so that none of the flight crew members called into question the last QNH received, i.e. 1 027 hPa, as opposed to the value received 12 minutes earlier, i.e. 1 019 hPa.

At 1403:18 UTC, the co-pilot told the captain he was going to enter the ILS frequency, and the captain answered "OK", after which the co-pilot referred to "ONE TEN THREE" and said that "AFTER TWO THOUSAND FEET WE'LL GET BELOW THESE CLOUDS", to which the captain answered "IN CASE WE DON'T ... ONE EIGHT SEVEN IS THE OUTBOUND".

At 1408:05 UTC, the GPWS began to sound a "WHOOP WHOOP PULL UP", which lasted seven seconds, without any comment or reaction from the crew.

At 1408:12 UTC, IDN 1851 flew into Pico Alto, at 36°58'48''N and 36°05'28''W and an altitude of 1 795 ft (547 m) (Annex 2).

Moments before the crash, the aircraft was seen flying over the Parish of Santa Bárbara, in a normal flight attitude and at an altitude considered below normal by the witnesses, heading towards Pico Alto, after which it flew into the clouds covering the mountain and immediately the thundering noise of the crash was heard.

1.1.2 Air Traffic Control

At 0939 UTC, the Bergamo Airport Air Traffic Services sent the flight plan for IDN 1851, which was to leave for Santa Maria at 1000 UTC.

The control assistant who received the message filled in the flight progress strips according to the route published in the AIP - Portugal.

At 1016 UTC, the Bergamo Airport ATS position sent notice of IDN 1851's departure. The control assistant activated the flight and the flight progress strips awaited transfer of control from the Western Sector of the Lisbon Area Control Centre to the respective Oceanic Sector of the Santa Maria Area Control Centre.

At 1205 UTC, The Western Sector of the Lisbon Area Control Centre transferred IDN 1851 to Oceanic Sector I of the Santa Maria Area Control Centre:

> "It is Independent one eight five one one eight five one MAKIN one two five one three five zero".

Oceanic Sector I accepted the transfer:

> "one two five one three five zero approved".

Between 1222:18 and 1225:53 UTC, nearly twenty messages were exchanged; IDN 1851 provided the estimate to MAKIN and the flight level and asked for information on the need for an oceanic clearance:

"one eight five one is estimating MAKIN one two five one we require to issue an oceanic clearance",

and,

"one eight five one is estimating MAKIN at one two one five I wanted to know if it's required receiving an oceanic clearance to fly from Lisbon to Santa Maria".

The Santa Maria Aeronautical Station tried to remain in contact with IDN 1851, giving the following answer to the second message:

"Roger you are requesting oceanic clearance from Lisbon to Santa Maria".

Between 1228:50 and 1232:27 UTC, nearly twenty messages were exchanged with IDN 1851, in which the Santa Maria Aeronautical Station tried to obtain the aircraft's SELCAL, without success.

At 1246:33 UTC, IDN 1851 was given oceanic clearance:

"Santa Maria Oceanic clears Independent one eight five one to proceed via MAKIN three eight north two zero west ECHO Sierra Mike Alpha flight level three five zero MACH decimal eight zero read back, read back".

Thirty-two seconds later, IDN 1851 read back:

"Independent one eight five one is clear to MAKIN three eight north two zero west to ECHO maintain flight level three five zero".

Santa Maria Radio corrected the readback, and again IDN 1851 repeated neither the destination navaid nor the MACH number. A second correction was made, but this time the only correction was to the MACH number, which was finally understood, and the aircraft's SELCAL (EMAL) was obtained.

As regards the destination navaid, IDN 1851 never confirmed that it was the SMA NDB.

Between 1301:09 and 1303:16 UTC, nearly ten messages were exchanged with IDN 1851 in order to transmit the frequencies on which the next position report was to be made, i.e. 127.9 MHz, there having been some difficulty in understanding on the part of the aircraft.

At 1329:25 UTC, the aircraft called the Santa Maria Aeronautical Station, on 127.9 MHz, and normally transmitted the 20W position report. IDN 1851 was instructed to contact Santa Maria Control, on 132.15 MHz, fifteen minutes before the ECHO point, which it did at 1335:03 UTC, estimating ECHO at 1355 UTC and informing that it was at FL 350. It was instructed to call upon reaching ECHO.

At 1343:57 UTC, IDN 1851 contacted Santa Maria Approach Control for the first time on 119.1 MHz to request the weather at Santa Maria. It received the 1300 MET REPORT (QNH 1 019).

IDN 1851 did not read back the QNH nor was it asked to.

At 1348:16 UTC, IDN 1851 again called Santa Maria Control, on 132.15 MHz, requesting clearance to descend; it was cleared to descend to FL 40 and instructed to call at the ECHO point.

At 1355:49 UTC, Santa Maria Control asked IDN 1851 to report the level it was descending through, which the aircraft informed was FL 220.

IDN 1851 reported ECHO at 1356:15 UTC and was instructed to contact the Santa Maria Aerodrome Control Tower on 118 MHz.

At 1349:20 UTC, the Santa Maria Aerodrome Control Tower contacted the terminal sector of the Santa Maria Area Control Centre to obtain IDN 1851's ECHO estimate.

> "He estimates ECHO at fifty-five passing about fourteen zero five at the station he is already descending to four zero and he is yours ah when he passes through level one one zero over".

At 1356:23 UTC, the Area Control Centre, TMA position, handed over to the Aerodrome Control Tower responsibility for providing ATC services to IDN 1851.

At 1356:35 UTC, IDN 1851 contacted the Santa Maria Aerodrome Control Tower for the second and last time on 118.1 MHz, to inform that it was passing through FL 200, descending to FL 40.

At 1356:47 UTC, in the Santa Maria Aerodrome Control Tower, the trainee controller at the position transmitted the meteorological information just received and cleared IDN 1851 to descend to 3 000 ft:

"Independent one eight five one roger recleared to three thousand feet on QNH one zero two seven and runway will be one niner ...".

After a pause, at 1356:59 UTC:

"Expect ILS approach runway one niner report reaching three thousand feet".

At 1357:05 UTC, he received the readback from IDN 1851:

"one zero two seven".

This message was accepted without requesting a readback of the last altitude clearance (3 000 ft) and was the last contact with IDN 1851.

The 1400 MET REPORT, received at 1354 UTC, specified a QNH value of 1 018.7 hPa, not 1 027 hPa as had been transmitted.

At 1408:12 UTC, when IDN 1851 flew into Pico Alto in Santa Maria, two air traffic controllers were on duty in the Aerodrome Control Tower: a supervisor and a trainee. These controllers came on duty at 1404 UTC according to the daily record of attendance, and they never succeeded in contacting IDN 1851.

The previous shift, which had provided aerodrome control services to IDN 1851, was also made up of two controllers, who had come on duty at 0900 UTC, a supervisor and a trainee. After the change of shift, they left the Aerodrome Control Tower at 1403 UTC.

The operations supervisor, who is responsible for staff on duty in the Area Control Centre and in the Santa Maria Aerodrome Control Tower, was at the usual place of work, i.e. the Area Control Centre room. The operations supervisor on the previous shift was still on duty.

2.0 ANALYSIS

2.1 GENERAL CONSIDERATIONS

The Board of Inquiry found that the aircraft was airworthy and that the weight and balance were within the established limits. There was no evidence of any mechanical or instrument failure before ground impact likely to have put the aircraft's safety at risk.

The Board firmly believes that the functioning of the aircraft was perfectly normal and in accordance with technical specifications, and that the route flown was in accordance with the instructions received by the crew.

The weather played a substantial role in the accident, since Pico Alto was covered in clouds (IMC conditions) and could therefore not be seen by the crew. Light conditions did not contribute in any way to the accident, since it occurred in broad daylight.

The Board therefore focused its analysis on communications and on crew and Air Traffic Control training and procedures.

2.2 DESCENT TO SANTA MARIA

3.3.1 Entry route

The operational flight plan supplied by Lockheed Data Plan, defining an arrival point designated as LPAZ with ground coordinates N36756 and W025096, which as mentioned above do not correspond with the ground coordinates of any of the Santa Maria navaids nor with those of the aerodrome reference point, was not developed according to the procedures established in the AIP - Portugal, which indicates as an entry route ECHO - NDB - SMA.

It was established by the Board that the aircraft was flying fairly accurately on a radio route from ECHO to the Santa Maria VOR (VSM VOR), a route very close to the one shown on the flight plan. Indeed, the VSM VOR identification is recorded on the CVR and the path established for the aircraft corresponds with the route referred to.

The oceanic clearance provided by the aeronautical station was clear as regards the route clearance: **"... to proceed via MAKIN three eight north two zero west ECHO SIERRA MIKE ALFA ..."**, a clearance which was repeated later with equal clarity. However, the Board firmly believes that the identification of the final fix of the route was never clearly understood by the crew. The two readbacks made were neglectful with regard to the final fix of the route. The first ended at the ECHO point and the second referred to **"... ECHO point then Santa Maria ..."**, a readback which ended up being accepted by the aeronautical station. It should be mentioned that the aircraft's SELCAL, which was requested immediately, was ECHO MIKE ALFA LIMA (EMAL); this sounds very similar to the designation of the final fix, "ECHO SIERRA MIKE ALFA", and the Board believes that, coupled with communication problems, this may have contributed to an unclear understanding by the crew of the terminal route.

However, both the path actually followed by the aircraft, leading to the VSM VOR, and the route shown on the flight plan were within the protection area for the route cleared from ECHO to SMA, 5 NM wide on either side of the centreline, and the Board considers that the aircraft was not flying on the route cleared and published in the AIP - Portugal, although it was within the protection area for this route.

It is the Board's opinion that non-publication in the AIP - Portugal of the restrictions on the use of the VSM VOR invited its use as a primary navigation aid in the terminal area. This contravened published procedures, since the use of a VOR in the definition of the ATS routes serving Santa Maria and of holding patterns is provided for in the planning criteria published in the Air Navigation Plan for the North Atlantic, North American and Pacific Regions (ICAO Doc. 8755/12). This Plan establishes that the primary navigation aid in a terminal area should be a VOR, which should be so located as to permit the most efficient ATS approach procedures, and that NDBs should be used for holding when the provision of VORs for this purpose is not possible or practicable. The Air Navigation Plan for the European Region (ICAO Doc. 7754/22) establishes identical procedures. Also, the Jeppesen area chart, normally used by flight crews, is unclear in this regard, as it shows the VSM VOR and the SMA NDB coupled in the same conspicuous box, leading one to conclude that the VSM VOR is also a navaid defining the nominal routes of the ATS route structure serving Santa Maria.

Therefore, because it is usual in the United States and in Europe to use a VOR to define ATS routes and holding patterns, because the crew had no knowledge of the restrictions on the VSM VOR, because it did not have a clear perception of the oceanic clearance it had been given, and in view of the information contained on the Jeppesen area chart and in the operational flight plan, a scenario was created which could have led the crew to consider the VSM VOR as the primary navigation aid in the terminal area.

Moreover, this procedure was frequently used by aircraft approaching Santa Maria Airport. Eyewitnesses even told the Board that it was usual for aircraft to fly over the Parish of Santa Bárbara heading for the airport, which would not occur if they headed for the SMA NDB, and that they had noticed the aircraft in question only because it was flying at an altitude lower than what they considered normal.

Although the path actually followed by the aircraft, i.e. ECHO - VSM VOR, and the route on the operational flight plan were within the protection area on the route cleared and published, i.e. ECHO - SMA NDB, the Board believes it is to be assumed that if the aircraft had headed for the SMA NDB, with the same navigational accuracy as was shown, it would not have flown into the ground. Indeed, it would in that case have followed a more northerly path, over the sea and over an area of the island with lower terrain, and although there would have been a loss of separation with the ground and a violation of the minimum sector altitude established in the AIP - Portugal, the aircraft would not have crashed into the ground.

2.2.2 Altimeter setting

As mentioned above, the METAR issued at 1256 UTC referred to a QNH of 1 019.1 hPa, and the METAR issued at 1354 UTC referred to a QNH of 1 018.7 hPa. The controller on duty in Santa Maria Approach Control gave the aircraft, at 1344:19 UTC, the QNH referred to in the METAR issued at 1256 UTC.

At 1356:47 UTC, when clearing IDN 1851 to descend to 3 000 ft and intending to provide the QNH in the METAR issued at 1354 UTC, the controller provided a QNH of 1 027 hPa instead of 1 018 hPa. It was not possible to determine what was at the root of this mistake. However, it should be mentioned that the inclusion of decimals in the METAR may have contributed to the mistake. Moreover, in accordance with the procedures established in the Manual of Aeronautical Meteorological Practice (ICAO Doc. 8896 AN/893/3) and in WMO Doc. FM IS VIII-Ext, the QNH should have been rounded down, i.e. to 1 018 hPa, and this value should have been included in the METAR. On the other hand, it is interesting to point out that the METAR was issued at 1354 UTC and that it was transmitted to the aircraft two minutes and forty-seven seconds later.

The Air Traffic Control Services received the MET Report about one minute before sending it to IDN 1851. During that time, according to established procedures, the controller should have familiarized himself with the content of the MET Report, compared it with the MET Report issued at 1256 UTC, checked that the QNH was different from the previous one and that the variation was normal, listened to the call and answered IDN 1851.

When answering the aircraft, the controller rounded off the numbers mistakenly and checked to see whether the wind at the entrance to runway 19 was the same as in the middle of runway 270/16. The simultaneity of these actions and the fact that the QNH had a decimal of 7 and that the wind was two seven zero may have contributed to the controller providing a QNH of 1 027.

It was determined that because of this error the aircraft was placed 240 ft (73.152 m) below the altitude indicated by the altimeter.

Since the aircraft engines struck the stone wall alongside the road on the top of Pico Alto and since the trees on the western slope must have been about 10 m higher, it can be assumed with a certain degree of probability that this difference may have contributed to the accident.

It should be emphasized that, irrespective of the QNH provided, the aircraft would still have been in a potentially dangerous situation, with a risk of flying into terrain as it descended to an altitude of 2 000 ft. However, if the crew had respected the minimum cleared altitude of 3 000 ft, the error that added an extra 9 hPa to the QNH would not have had any consequence.

2.2.3 Communications

On all frequencies used for communications with IDN 1851 or related to it, it was found that there were many errors and inaccuracies in the language used, standard phraseology was not used and the communications technique was poor, on the part of the aeronautical station and ATC units as well as on the part of the aircraft, with special emphasis on the latter.

Thus, irregular forms of enunciation of numbers were used, as well as non-recommended expressions of courtesy, and the word "decimal" was not used to separate the main part from the decimal part of radio frequencies.

In the communications transmitted by the ATC units, it should be mentioned that in the meteorological information provided by the approach sector of the Area Control Centre at 1343:57 UTC, the word "at" was improperly used in the expression **"one octa at one two zero"**, which on board the aircraft sounded like **"one octa two two zero..."**, leading the crew to assume that below two thousand feet they would be below the clouds, as can be heard from the CVR.

As regards the communications transmitted by the aircraft, it should be mentioned that on the frequency 13 306 KHz the aircraft used the frequency for four periods of time, for a total of twenty-three minutes, during which it transmitted twenty-eight messages correcting and confirming the contents of six messages and forty-nine messages to establish, extend or interrupt contact. This points to a poor communications technique, which was perhaps due to the fact that the co-pilot had limited experience or that he was not concentrating on the tasks in hand.

In the HF and VHF communications, seventeen groups of numbers were transmitted, with a maximum of four numbers, and eight had to be repeated, because of an obvious lack of comprehension by the pilot, which again shows a poor communications technique as well as the use of non-standardized phraseology.

During the message from the Aerodrome Control Tower which cleared the flight to descend to three thousand feet, the co-pilot began his transmission by reporting his understanding of the descent clearance provided, talking over the continuation of the message from the Tower, which was requesting a report at three thousand feet. In this way, neither did the Tower notice the error made by the crew regarding the altitude clearance, nor was the crew able to receive the final part of the message from the Tower, i.e. "report reaching three thousand".

This procedure not only shows once again that the co-pilot did not adhere to recommended procedures and used a poor communications technique, in the Board's opinion it also contributed to the accident.

2.2.4 Crew procedures

It was established that at the time of the accident the aircraft was being flown by the captain, while the co-pilot was carrying out communications, a procedure in accordance with company regulations (Operations Manual, Bulletin # 6), in view of the co-pilot's limited experience.

After being cleared for approach (ILS to runway 19) at 1356:47 UTC, the crew should have performed the approach briefing, which includes a review of the approach plate, minimum safety altitude, etc., as specified in Independent Air's "Operations Manual" and "707 Flight Handbook". This was not done, clearly violating established operating rules.

If the approach plate had been properly examined, it would certainly have been noticed that the minimum sector altitude was 3 000 ft, not 2 000 ft as had been understood, and the existence of Pico Alto, clearly marked on the chart, would also have been noticed. The crew would then have questioned their understanding of the clearance given by Santa Maria Approach Control, they would have asked Approach Control about it, and the accident would have been avoided.

Moreover, under ICAO Doc. 4444-RAC/1801/12, "Rules of the Air and Air Traffic services, Part II, 1", the objectives of air traffic control services, as prescribed in Annex 11, do not include prevention of flight into terrain. The procedures described in the document therefore do not relieve the pilot of his responsibilities to ensure that any clearance received from air traffic control units is safe in this regard, except when under IFR radar vectors, which did not occur in this case.

It should also be emphasized that, as specified under "Independent Air 707 Flight Handbook - Crew coordination - General", after an ATC clearance is received and confirmed, the pilot at the controls, in this case the captain, should repeat aloud his understanding of the clearance so that all crew members will be aware of its contents, namely the sector altitude. Once again it appears that this procedure was not followed. Indeed, when the co-pilot repeated his understanding of the clearance from Santa Maria Aerodrome Control Tower, "cleared to two thousand feet", one of the crew members can be heard on the CVR saying "three thousand". However, there was no rectification by the co-pilot in spite of the correction made by one of the other crew members, nor did the other crew members take any initiative in this regard, and the passivity displayed in the face of this situation must be emphasized.

One of the pilots also entered the 2 000 ft in the "altitude alert" without any of the other two crew members raising any objection, contrary to the procedures established under "Independent Air 707 Flight Handbook, Altitude Alert", according to which the minimum altitude on the charts must be entered, which also shows that these charts had not been reviewed.

The GPWS sounded its ground proximity alarm for seven seconds, alerting the crew to a potentially dangerous situation. Strangely, the crew did not make any comment or try to act to remove the aircraft from that situation, in accordance with the company's "Operations Manual" and "707 Flight Handbook", once again clearly violating established operating standards.

It should be pointed out that the crew had sufficient time to try to remove the aircraft from this situation, since the pilot's reaction time in the event of a GPWS alarm is on average about 5.4 seconds based on information from various air carriers.

As regards the QNH, the crew received a first value of 1 019 hPa, followed twelve minutes later by a second value of 1 027 hPa.

Since a variation of more than 9 hPa in the QNH is impossible in such a short lapse of time, one cannot understand how the second value, although it was questioned by the co-pilot himself, ended up being accepted passively and entered into the altimeters and "altitude alert", again indicating a serious lack of concentration. In addition, since the QNH units had not been transmitted, in accordance with the instructions in the Independent Air 707 Flight Handbook, the crew should have questioned the aeronautical station to remove any doubt, which again was not done.

According to the company's Operations Manual - "Captain Duties and Responsibilities", the captain is obliged to direct the activities of the other crew members and to ensure adherence to established operating procedures, which was not done.

Indeed, during this flight stage, the crew had informal conversations, indicating a relaxed mood.

A female voice can also be heard on the CVR recording, leading one to assume that one of the cabin crew members was in the cockpit.

Both these situations violate the provisions of the company's Operations Manual, which establishes that under 10 000 ft, crew conversations must be kept to the minimum necessary, and prohibits cabin crew members from entering the cockpit during critical flight stages, except in case of emergency or when called by the captain.

The company's Operations Manual establishes also that in operations outside the USA, standard phraseology must be used in communications, which again did not occur. Instead, non-standard language and a poor communications technique were used.

Based on the above, it is clear that the crew did not adhere to the operating procedures stated in the company's manuals, a fact which played a pivotal role in the occurrence of the accident. Furthermore, the Board understands that during the critical moments of the flight, the crew showed a remarkable lack of clear-sightedness and attention, leading one to wonder whether the rest time they were given was used in the best way.

2.2.5 Air traffic control procedures

The Board did not detect in the organization of the Santa Maria Air Traffic Control Services or in the established procedures any factor which could have contributed to the accident.

With regard to the period between 1300:00 and 1344:56 UTC, it was found that the calls made to the Aerodrome Control Tower were not answered and that information from entering aircraft, which should have been transmitted by the Tower to Airport Operations, was provided by the Area Control Centre and subsequently confirmed by the Tower. It can therefore be assumed that the Tower was deserted until very close to the first contact with IDN 1851, on 119.1 MHz, which indicates some complacency in the running of the service.

The Board also deems it necessary to mention the violation of established procedures committed by the controllers on duty in the Aerodrome Control Tower when they accepted the incomplete readback of their clearance to descend to three thousand feet, which the Board believes contributed to the accident.

Indeed, if a complete readback of the clearance had been requested, the trainee controller at the position would have noticed the crew's incorrect understanding of the descent clearance, as a result of which he could have made a correction, thereby preventing the aircraft from descending to two thousand feet.

Such a situation was accepted by the supervising controller on duty at the position, who did not correct the procedural error. However, it is possible that she did not follow the transmission of the message since she was on the telephone with the Movement services, not being able therefore to pay due attention to the communications with the aircraft. She did however question the controller about the QNH callback, indicating initial concern that the activity should be carried out properly.

The fact that the telephones are fitted only with a sound-giving call system that cannot be disabled may constitute a disruptive and distracting factor and originate errors or omissions.

The fact that this last communication was made very close to the time of shift changeover may also have contributed to the above procedural violation. Indeed, the last communication with IDN 1851 was received at 1357:05 UTC, and the shift was ending at 1415 UTC, including fifteen minutes' overlap with the next shift, which was to come in at 1400 UTC.

The new shift signed in at 1404 UTC; therefore, it must have reached the Tower a few minutes earlier to take over, and one cannot rule out some disruption and haste in the previous shift coming off duty, which occurred at 1403 UTC according to their own statements.

2.3 Crew training and qualifications

The crew was duly qualified for the flight, holding appropriate licences and medical certificates.

The crew's instruction and training were in accordance with FAR Part 121, with completion of appropriate courses. However, one cannot help analyzing the co-pilot's instruction and training upon joining the company.

The co-pilot's flight training included two simulator sessions and a third in which he took a test (checkride), for a total of 5 hours at the controls and 6 hours as an observer, a time which the Board believes was clearly insufficient though in accordance with FAR Part 121, which allows reductions in minimum times. In addition, after the second simulator mission, the instructor believed that the trainee needed some more practice, although he showed progress.

In spite of this recommendation, the co-pilot's testing was brought forward to the next session, without the co-pilot receiving the additional training referred to. It should be emphasized also that his experience on this type of aircraft was limited (64 hours), that he had started airline operations fifteen days before the date of the accident and that he was on his first flight to Santa Maria.

With regard to GPWS training, it was clearly demonstrated that this had not been performed, which may have contributed decisively to the pilots' failure to react in good time to the ground proximity alarm. On the other hand, in accordance with FAR Part 121, paragraph 121-407, the simulator should accurately reproduce the aircraft's performances, which did not occur in this case.

The crew's actions at times during the flight, which demonstrated non-adherence to particular procedures amounting to specific operating doctrine, are generally indicative, in the Board's opinion, of insufficient training in the routines of each crew member, as well as in the coordination of joint tasks, which may have contributed significantly to the occurrence of the accident.

2.4 FAA oversight

The number of FAA inspections is within average for this type of operator. However, it was not possible to determine the effectiveness of such inspections.

As regards international operations, the NTSB believes, as does the Board, that in view of the differences in procedures, navaids and air traffic controllers' pronunciation relative to the USA, for the FAA to be able to carry out inspections adequately, FAA inspectors would have needed specific training. Therefore, although twelve line inspections on international routes had been carried out, it is believed that the inspectors did not have adequate experience and knowledge.

In view of the above, it is believed that the FAA should set up a unit specialized in international operations, to provide technical assistance to operations inspectors who inspect air carriers engaged in such operations.

Such a unit should check periodically whether flight crew procedures and training are adequate and address the above-mentioned factors, which can affect this type of operation.

On the other hand, as mentioned earlier, the pilots had limited experience of international operations and in the airspace where they were operating.

The NTSB had previously drawn the FAA's attention to the need to establish minimum experience requirements for all crew members, based on previous accidents, at which time it had made the following recommendation:

"A-88-137

Establish minimum experience levels for each pilot-in-command and second-in-command pilot, and require the use of such criteria to prohibit the pairing on the same flight of pilots who have less than the minimum experience in their respective positions."

As far as GPWS training is concerned, the situation at Independent Air, where the GPWS was inhibited or the pilots were instructed not to react to the alarm, not only violated the FAA's directives to its operations inspectors, but also created a potentially dangerous situation since the pilots were instructed, explicitly or implicitly, to disregard GPWS alarms.

2.5 AERONAUTICAL INFORMATION FOR THE FLIGHT INFORMATION REGION SANTA MARIA

Aeronautical information issued by ANA,EP on the authority and under the responsibility of the General Directorate for Civil Aviation is essentially included in the AIP - Portugal and was analyzed by the Board in relation to the Flight Information Region Santa Maria.

The Board found that words from the ICAO phonetic alphabet were used to designate significant points on the lateral boundary of the terminal control area Santa Maria, which contributed to the fact that the route defined in the oceanic clearance was not clearly understood by the crew and that the controller on duty had difficulty understanding the aircraft's SELCAL.

The Board found other anomalies in the aeronautical information for Santa Maria that it felt it should mention, although they did not have any bearing on the occurrence of the accident.

For instance, although the Portuguese Republic has adopted without exceptions the international rules in Annexes 2, 4, 10, 11, 14 and 15 to the Convention on International Civil Aviation, there are discrepancies between the national legislation and the international rules referred to with respect to certain definitions and procedures, which on the whole are less restrictive than the international procedures and consequently do not provide the same protection.

It was also found that aeronautical information for this region, included in the AIP - Portugal, was not properly updated, containing many errors, omissions and inaccuracies, and was not in conformity with the international rules in force adopted by the Portuguese Republic.

Regarding aeronautical charts, for twenty-seven years handwritten corrections were used without the proper registration and without quality, which was not the case with the remaining aeronautical charts of other airports, which had their charts reviewed between 1984 and 1988, with the exception of one chart from 1973. The accumulation of handwritten amendments and annotations and the significant change in instrument approach procedures by themselves required a revision of these charts, which did not occur, in violation of the rules for revising aeronautical charts.

In addition, none of the charts is in accordance with all of the relevant standards in Annex 4 to the Convention on

International Civil Aviation; therefore the charts are unduly referred to as ICAO charts.

In the Board's opinion, such situations show the neglected state in which the region's aeronautical information was left.

The Board believes it is necessary to emphasize the inaccuracies and omissions relating to the minimum altitudes determined by the erection of the RTP television antenna, which in the opinion of the Board endangers flight safety in the area.

2.6 HUMAN FACTORS

2.6.1 Crew

As far as the crew is concerned, certain medical and mental facts came to light. The captain had had foot surgery, the co-pilot self-medicated with antihistamines and the flight engineer had recently undergone psychiatric treatment, which indicates that the crew may not have been in an ideal physical and mental condition. However, it was not possible to determine to what extent these circumstances interfered with the psychic "availability" necessary for performing duties.

Although these circumstances do not show a clear direct relation with the causes of the accident, they lead one to wonder how they may have adversely affected such important factors as capacity for and timing of decision-making, normal carrying out of procedures, and concentration at less favourable times.

It should be emphasized that these circumstances were not mentioned in the crew members' medical records held by the FAA and that according to the "Independent Air Operations Manual - Returning to Flight Duty", a crew member who returns to duty after an illness must inform the chief pilot that he has recovered, and the chief pilot may require the crew member to take a medical exam before returning to flight duty, which as far as the Board was able to ascertain did not occur, at least after the captain's operation.

2.6.2 Air traffic controllers

In the psychological profile established by ANA,EP for selecting air traffic controllers, this activity was considered as non-routine, as far as the Board was able to ascertain, and the trainee air traffic controller at the position, who displays "possible qualitative fluctuations when faced with less motivating (routine) situations" according to the personality analysis carried out during the selection process, was considered suitable for the duty.

The Board believes that air traffic control is a routine activity mainly in airspaces with few movements and therefore few problems, as is the case with the Santa Maria Aerodrome Control Tower. This position is in line with the policy maintained by IFATCA (International Federation of Air Traffic Controllers'

Associations) for the selection and training of air traffic controllers.

One might wonder to what extent the above personality characteristic may or may not have influenced the normal performance of the air traffic controller's duties.

3.0 CONCLUSIONS

3.1 Established facts

3.1.1 The aircraft was airworthy and duly certified for the flight.

3.1.2 The aircraft's weight and balance were within the limits authorized. The calculation errors discovered had no influence whatsoever on the occurrence of the accident.

3.1.3 No operating failures of the aircraft or of its equipment were detected that may have reduced safety or increased crew workload during the final stage of the flight.

3.1.4 The air traffic controllers were duly qualified.

3.1.5 The crew was duly licensed, qualified and certified to operate the aircraft.

3.1.6 The crew and air traffic controllers' work schedules were in accordance with regulations in force.

3.1.7 The crew deliberately descended to 2 000 ft, in violation of the minimum sector altitude, i.e. 3 000 ft, published on aeronautical charts and cleared by the Santa Maria Tower.

3.1.8 There was an overlap of communications between the Aerodrome Control Tower and the aircraft when the Tower transmitted the clearance to descend to 3 000 ft. Before the Tower completed its message, the co-pilot started reading back his understanding of the clearance. As a result, the controller did not notice the crew's mistake and the crew did not receive the final part of the Tower's message requesting a report at 3 000 ft.

3.1.9 The air traffic controller on duty in the Aerodrome Control Tower accepted the incomplete readback of his descent clearance - "1027" - and therefore did not notice that the crew had misunderstood it.

3.1.10 The Santa Maria Aerodrome Control Tower did not provide the correct QNH, making an error of more than 9 hPa, which put the aircraft 240 ft below the altitude shown in the cockpit.

3.1.11 The crew did not perform the approach briefing, which includes review of the approach plate, as established in the company's operating procedures.

3.1.12 The crew violated the company's operating procedures, namely with reference to repeating aloud the descent clearance, informal conversations in the cockpit at altitudes below 10 000 ft, and the presence of other than flight crew members in the cockpit during critical flight phases.

3.1.13 The GPWS worked properly for seven seconds.

3.1.14 The crew did not react to the GPWS alarm as provided for by the company's operating procedures.

3.1.15 The crew did not receive adequate training in reacting to the GPWS alarm.

3.1.16 The crew, especially the co-pilot, had limited experience in international operations.

3.1.17 The aircraft was not on the route cleared and published in the AIP - Portugal, although it was within the protection airspace on that route.

3.1.18 The operational flight plan, whose final destination was not the SMA beacon, was not developed in accordance with the AIP - Portugal.

3.1.19 The navaids were working normally, and there were restrictions on the VSM VOR which were not published in the AIP - Portugal.

3.2 PROBABLE CAUSES

3.2.1 Causes

The Board of Inquiry understands that the accident was due to the non-observance by the crew of established operating procedures, which led to the deliberate descent of the aircraft to 2 000 ft, in violation the minimum sector altitude of 3 000 ft, published in the appropriate aeronautical charts and cleared by the Santa Maria Aerodrome Control Tower.

3.2.2 Other factors

The Board of Inquiry understands that the following factors contributed in some way to the occurrence of the accident:

3.2.2.1 Transmission by the Santa Maria Aerodrome Control Tower of a QNH value 9 hPa higher than the actual value, which put the aircraft at an actual altitude 240 ft below that indicated on board.

3.2.2.2 Deficient communications technique on the part of the co-pilot, who started reading back the Tower's clearance to descend to 3 000 ft before the Tower completed its transmission, causing a communications overlap.

3.2.2.3 Violation by the Aerodrome Control Tower of established procedures by not requiring a complete readback of the descent clearance.

3.2.2.4 Non-adherence by the crew to the operating procedures published in the appropriate company manuals, namely with respect to cockpit discipline, approach briefing, repeating aloud descent clearances, and informal conversations in the cockpit below 10 000 ft.

3.2.2.5 General crew apathy in dealing with the mistakes they made relating to the minimum sector altitude, which was known by at least one of the crew members, and to the ground proximity alarms.

3.2.2.6 Non-adherence to standard phraseology both by the crew and by Air Traffic Control in some of the air-ground communications.

3.2.2.7 Limited experience of the crew, especially the co-pilot, in international flights.

3.2.2.8 Deficient crew training, namely concerning the GPWS as it did not include emergency manoeuvres to avoid collision into terrain.

3.2.2.9 Use of a route which was not authorized in the AIP - Portugal.

3.2.2.10 The operational flight plan, whose final destination was not the SMA beacon, was not developed in accordance with the AIP - Portugal.

4.0 RECOMMENDATIONS

4.1 Recommendations made by the NTSB to the FAA, with the concurrence of the Board of Inquiry

4.1.1 Set up within the FAA a group of specialists in international operations, in order to provide inspectors responsible for monitoring carriers engaged in operations of this type with guidance and assistance in their oversight tasks. (Class II, Priority Action) (A89-44)

4.1.2 Provide carriers engaged in international operations with guidance on operations of this type and information on the factors that may affect flight safety. (Class II, Priority Action) (A89-45)

4.1.3 Ensure that the operating procedures and training programmes of carriers engaged in international operations are periodically reviewed by a group of specialists in operations of this type, to check whether the factors which may affect the safety of these operations are adequately addressed. (Class II, Priority Action) (A89-46)

4.1.4 Review FAA-approved training programmes and manuals of carriers operating aircraft equipped with a GPWS and in accordance with the requirements of 14CFR Part 135 and 14CFR Part 121, to check whether crews are trained and required to immediately implement manoeuvres to avoid collision into terrain when the GPWS alarm goes off and the terrain cannot be identified visually or the existence of a safe distance to terrain cannot be established by other means. (Class II, Priority Action) (A89-47)

4.1.5 Establish for captains and co-pilots minimum levels of experience required for international operations, and prohibit international flights in which neither pilot has the minimum level of experience established. (Class II, Priority Action) (A89-48)

4.1.6 Encourage pilots to report unusual flight experiences in international operations, for NASA's Aviation Safety Reporting System. (Class II, Priority Action) (A89-49)

4.2 Recommendations by the Board of Inquiry

4.2.1 The Board of Inquiry found that the minimum flight altitude on ATS routes or route segments passing over the SMA NDB and the minimum sector altitude of Santa Maria Airport, indicated in the AIP - Portugal, are not determined as a function of the height of the RTP television antenna located on Pico Alto, and that the minimum altitude for the area is not determined.

The Board recommends that the above be revised in accordance with the rules established in Annexes 4 and 11 to the Convention on International Civil Aviation, taking account of the height of the above-mentioned RTP antenna.

4.2.2 The Board of Inquiry found that in the designation of the significant points of the Santa Maria TMA lateral boundaries, words of the ICAO phonetic alphabet were used, which is contrary to the standards in Annex 11 to the Convention on International Civil Aviation and can create confusion in the communications between aircraft and air traffic control, and that there was no designation of published routes.

The Board recommends that the designation of the said points be made in accordance with the above-mentioned international standards and that designations be assigned to the above-mentioned routes.

4.2.3 The Board found that the use of the VSM VOR is classified as restricted, but that this information does not appear in the "AIP - Portugal, Radio Communications and Navigation Facilities - COM 2-9"; it therefore recommends that a NOTAM be published with the lateral and horizontal boundaries of the sector within which the VSM VOR should not be used, and that this information be introduced as soon as possible into the AIP - Portugal.

4.2.4 The Board found that there were various errors and omissions relating to the Santa Maria area in the aeronautical information published in the AIP - Portugal, that some aeronautical charts do not exist and that others are out of date; it therefore recommends that all aeronautical information on the area contained in the AIP - Portugal be reviewed and updated in accordance with the standards in Annexes 4 and 15 to the Convention on International Civil Aviation.

4.2.5 The Board found that the World Aeronautical Chart - ICAO 1:1 000 000, sheet Nos 2350 and 2351, the basic chart for all the aeronautical information on the area, is out of date and out of print since 1976; it therefore recommends the publication of an update as soon as possible.

4.2.6 The Board found that the procedures for entry into the Santa Maria TMA do not comply with the requirements of the Air Navigation Plan for the North Atlantic, North American and Pacific Regions (ICAO Doc. 8755/12) as regards the use of the VSM VOR in the definition of the ATS routes serving Santa Maria and in the definition of holding pattern; it therefore recommends that these procedures be revised in order to comply with the planning requirements referred to.

4.2.7 The Board found that in the METARs provided to Air Traffic Control, the QNH value included decimals, contrary to the recommendations in Annex 3 to the Convention on International Civil Aviation and to WMO Doc. FM IS VIII - Ext METAR, which indicate that the QNH value must be rounded down, not including decimals; it therefore recommends that the procedures followed in recording the QNH value in METARs be amended, in accordance with the international standards referred to above.

ICAO Note.— Only sections 1.1, 2, 3 and 4 were translated from the Portuguese report.

ICAO Ref.: 009/89

No. 3

Fairchild Hiller FH227 B, F-GGDM, accident at Léoncel (26), France on 10 April 1989.

Report released by the Investigation Commission, France

SYNOPSIS

Date de l'accident :

Lundi 10 avril 1989, à 19 h 07 UTC (*)

Lieu de l'accident :

Léoncel (26).

Nature du vol :

Vol régulier, transport public de passagers, ligne EAS 602 Paris-Orly-Valence-Chabeuil.

Aéronef :

Fairchild Hiller FH 227 B ; immatriculation : F-GGDM.

Propriétaire :

Société BNP Bail, 23, rue de Marignan, 75008 Paris.

Exploitant :

Société Uni-Air International, aéroport de Toulouse-Blagnac, 31700 Blagnac.

Personnes à bord :

2 PNT ; 1 PNC ; 19 passagers.

Résumé de l'accident :

A la suite d'une erreur de navigation, l'avion percute la falaise de La Pierre-Chauve dans les contreforts du Vercors pendant la phase d'arrivée à l'aéroport de Valence.

1. RENSEIGNEMENTS DE BASE

1.1. *Déroulement du vol*

Le 10 avril 1989, le FH 227 B immatriculé F-GGDM de la compagnie Uni-Air International affrété par Europe Aéro Service décolle de Paris-Orly à 17 h 55 à destination de Valence-Chabeuil avec vingt-deux personnes à bord (dix-neuf passagers et trois membres d'équipage). Il assure le vol régulier 602 sous l'indicatif d'appel radiotéléphonique EY 602 GA. Le commandant de bord a déjà effectué plusieurs fois ce trajet avec le même aéronef.

Le vol se déroule normalement au niveau de vol 130 suivant la route prévue au plan de vol. Il passe le radiophare omnidirectionnel à très haute fréquence (VOR) de Nevers (NEV) à 18 h 23. Peu après le survol du VOR de Moulins (MOU), le contrôle régional de Paris le transfère au contrôle régional de Marseille qui le transfère à son tour au contrôle d'approche de Lyon à 18 h 42 peu avant le passage de Lespi (intersection du radial 163 du VOR MOU et du radial 298 du VOR LSA). A 18 h 43, le contact radio est établi avec le contrôle d'approche de Lyon qui l'autorise selon la route standard Lespi-verticale VOR VNE (situé près de Vienne), c'est-à-dire suivant une route magnétique 133°.

A 18 h 49, le F-GGDM est autorisé à débuter la descente vers le niveau de vol 70, puis à 18 h 55, en approchant de VNE il est autorisé à poursuivre la descente vers le niveau de vol 60 et à virer à droite vers la radiobalise non directionnelle à moyenne fréquence de Valence (VE) en suivant la route magnétique 178°. Au passage de VNE, à 18 h 56, il vire effectivement à droite mais suit une route magnétique orientée 155°. Deux minutes plus tard, à 18 h 58, l'approche de Lyon le transfère à l'approche de Valence avec laquelle il établit le contact radio trente secondes plus tard. Il est alors autorisé à poursuivre sa descente vers l'altitude de 3 500 pieds, soit 1 067 mètres, sur la route spécifiée d'arrivée VNE-VE.

L'avion poursuit sa descente en suivant une route magnétique 155° jusqu'à 19 h 04. Il vire alors à droite au cap 200° pour rejoindre puis suivre une route magnétique 178° en maintenant une altitude légèrement supérieure à 3 500 pieds.

A 19 h 07, il percute la falaise de la Pierre-Chauve (44° 57 Nord, 05° 09 Est) près du col de Tourniol dans les contreforts du Vercors (commune de Léoncel) à une altitude topographique de 1 260 mètres.

1.2. *Tués et blessés*

BLESSURES	MEMBRES d'équipage	PASSAGERS	AUTRES personnes
Mortelles	3	19	0
Graves	0	0	0
Légères. - Aucune	0	0	0

1.3. *Dommages à l'aéronef*

L'aéronef est entièrement détruit.

1.4. *Autres dommages*

La cargaison (150 kg) est entièrement détruite.

La zone de l'accident étant relativement désertique, seuls quelques arbustes situés en contrebas du point d'impact ont été heurtés par les débris.

1.5. *Renseignements sur le personnel*

a) Equipage de conduite :

Commandant de bord :

Homme, quarante-neuf ans.

Brevet de pilote professionnel de première classe (PP1) n° 2954 délivré le 7 juin 1974, licence correspondante validée jusqu'au 31 octobre 1989 (dernière visite médicale effectuée le 22 mars 1989 au C.E.M.P.N. de Paris. - Apte sans restriction. - Pas de dérogation médicale).

L'étude du dossier médical ne permet pas de mettre en évidence d'éléments susceptibles d'avoir eu une influence sur l'accident.

Stage de qualification Transport (SQT n° 115) effectué au Centre d'instruction des équipages de transport (C.I.E.T.) de l'armée de l'air de mars à juillet 1966 ;

Première présentation à l'épreuve hors-ligne du P.P. 1 le 10 mai 1973 ;

Complément d'entraînement effectué à l'issue de ce contrôle au C.I.E.T. en novembre 1973 puis février-mars 1974 pour une durée de vingt et une heures vingt ;

Seconde présentation et épreuve en ligne subies avec succès le 25 mars 1974 ;

Qualifié sur FK 27 le 9 décembre 1987, a suivi un stage théorique FH 227 au C.I.P.R.A. de Dinard du 23 au 24 novembre 1988 ;

(*) Les heures figurant dans ce rapport sont exprimées en temps universel coordonné (UTC). Il convient d'y ajouter deux heures pour obtenir l'heure légale en France le jour de l'accident.

Heures de vol, avant le vol de l'accident :

- total : 8 970 heures dont 577 sur FK 27/FH 227 ;
- dans les soixante derniers jours : 98 heures 30 ;
- dans les trente derniers jours : 31 heures 45 ;
- dans les dernières vingt-quatre heures : 3 heures 20 ;

Employé par la société Uni-Air International depuis le 1er octobre 1988.

Copilote :

Homme : cinquante-neuf ans.

Brevet de pilote professionnel n° 1572 délivré le 24 février 1965, licence correspondante validée jusqu'au 17 avril 1989 (dernière visite médicale effectuée le 12 octobre 1988 au C.E.M.P.N. de Paris. – Apte sans restriction. – Pas de dérogation médicale).

L'étude du dossier médical ne permet pas de mettre en évidence d'éléments susceptibles d'avoir eu une influence sur l'accident.

Qualifié sur FK 27 le 27 juillet 1979 après stage théorique au C.I.P.R.A. et pratique à Air-Martinique puis complément théorique FH 227 au C.I.P.R.A. les 12, 13 et 14 mars 1988.

Heures de vol, avant le vol de l'accident :

- total : 15 639 heures ;
- dans les soixante derniers jours : 71 heures 30 ;
- dans les trente derniers jours : 45 heures 08 ;
- dans les dernières vingt-quatre heures : 1 heure 20 ;
- sur FK 27/FH 227 : non connues.

Employé par la société Uni-Air International depuis le 1er avril 1987.

b) Personnel navigant commercial :

Femme, quarante-huit ans ;

Certificat sécurité sauvetage n° 8254 ;

Etait employée par la société Uni-Air International depuis le 26 avril 1978.

c) Personnels des services de la circulation aérienne :

Lyon-Satolas ;

Au moment de l'accident et conformément aux consignes d'exploitation en vigueur, quatre positions de contrôle étaient ouvertes à Lyon-Satolas :

- la position chef de quart ;
- la position approche ;
- la position tour ;
- la position sol.

Chaque position était tenue par un contrôleur possédant la qualification requise pour tenir le poste.

Valence-Chabeuil :

Conformément aux consignes d'exploitation en vigueur à Valence, un seul contrôleur était en service. Il assurait les services de la circulation aérienne sur une position où étaient regroupées la position contrôle d'approche et la position contrôle d'aérodrome.

Ce contrôleur possédait la qualification approche et la qualification contrôle d'aérodrome requises pour exercer à Valence.

1.6. *Renseignements sur l'aéronef et l'exploitant*

Uni-Air International.

Créée en 1969, la société Uni-Air est devenue maintenant une filiale de la nouvelle société Uni-Air International qui assure la grosse majorité du trafic du groupe ainsi constitué.

L'activité des deux sociétés repose principalement sur des vols de transport public à la demande, mais aussi sur des lignes régulières en affrètement d'autres sociétés et sur le transport de fret.

Au moment de l'accident, la société comprenait trois secteurs :

Secteur F 27 (2 F 27 et 2 FH 227) dont l'un des avions était affecté à la ligne Paris-Valence ;

Secteur réacteur : Corvette, Learjet, Falcon 20 (11 avions) ;

Secteur moins de 5,7 tonnes : Beech 99, Twin Otter (huit avions).

Elle utilisait une soixantaine de pilotes.

La dernière autorisation de transport aérien attribuée à la compagnie datait du 15 décembre 1988. Elle était autorisée à effectuer des transports à la demande de passagers et de fret dans le monde entier avec des avions de moins de 15 tonnes. Elle était également autorisée à effectuer des transports à la demande à l'aide de F 27 et de Fairchild 227 en Europe et dans les pays riverains de la Méditerranée.

Cellule :

Constructeur : Fairchild Industries ;

Type : FH 227 B ;

N° de série : 532 ;

Année de construction : 1967 ;

Certificat de navigabilité : 109603 délivré le 3 juin 1988, validé jusqu'au 6 septembre 1991 ;

Certificat d'immatriculation : n° B 16908 du 26 juillet 1988.

Au jour de l'accident l'appareil totalisait 27 249 heures de vol dont 2 054 heures depuis la dernière grande visite, et 39 128 atterrissages.

Moteurs :

Constructeur : Rolls Royce ;

Type : DART 532 - 7 :

	Gauche	Droit
N° de série	13 526	15 153
Temps de fonctionnement total	41 879 h	7 744 h
Temps de fonctionnement depuis dernière RG	2 379 h	4 517 h

Hélices :

Constructeur : Dowty Rotol :

	Gauche	Droite
	DRG/343/67	DRG/39/65
Temps de fonctionnement total	11 925 h	17 084 h
Temps de fonctionnement depuis RG	1 722 h	3 810 h

Equipements :

L'équipement de l'avion satisfaisait aux règlements applicables aux avions exploités en transport public.

La disposition des commandes et des indicateurs sur la planche de bord de même que les moyens d'affichage des aides radio-électriques sur les différents indicateurs n'était pas d'une grande logique. Ainsi, si l'équipage désirait utiliser le DME de LSA, il devait :

- utiliser le DME 1, le seul permettant d'afficher la fréquence 114,75 ;
- afficher préalablement la fréquence VOR 114,75 ;
- passer ensuite sur la position HOLD.

Après ces opérations, l'indication DME par rapport à LSA (114,75) demeurait même si l'équipage sélectionnait une autre fréquence VOR.

De plus, cette disposition n'était pas identique sur tous les avions de type F 27 ou FH 227 utilisés par la compagnie.

Entretien :

Avant l'acquisition de l'avion par Uni-Air International, la dernière visite importante (PV 3 : visite de 600 heures) avait été effectuée par Air Polynésie qui l'exploitait alors. Depuis son acquisition en juin 1988, seules des visites mineures ont été effectuées, la dernière l'ayant été par TAT le 18 mars 1989.

L'examen des derniers comptes rendus matériel (C.R.M.) fait apparaître que, parmi les travaux différés, seuls ceux liés au radar météorologique concernent la navigabilité : le 7 avril 1989, l'équipage a signalé l'apparition d'un problème de faisceau tremblotant rendant le radar inutilisable dans un secteur de 1° à 2°. Après recherche par les services d'entretien, il a été constaté que cette anomalie était due à une mauvaise rotation de l'antenne et était donc d'origine mécanique. Il convient de préciser que ce mauvais fonctionnement ne concernait qu'un faible secteur de l'écran.

Masse et centrage :

Le devis de masse et de centrage relatif à ce vol n'a pu être retrouvé ni à l'aérodrome de départ, ni sur les lieux de l'accident.

Avant le départ du dernier vol, il avait été embarqué 1,4 tonne de carburant (JET A 1).

Compte tenu du carburant et des passagers embarqués (19), la masse au moment de l'accident était bien au-dessous de la masse maximum autorisée.

Quelle qu'ait été la répartition réelle des passagers dans la cabine, le centrage n'a manifestement joué aucun rôle dans cet accident.

1.7. *Conditions météorologiques*

1.7.1. Conditions générales

Situation en altitude :

Zone de basses pressions sur l'Atlantique, au Nord du 50e parallèle, se prolongeant en un vaste thalweg axé des Iles Britanniques à la France et à l'Algérie ;

Au niveau de vol 130, le long du trajet : vent de 210° puis 190°/40 kt, et, en descente, au niveau 50 : vent de 220°/25 kt ;
Isothermes 0 °C : 2 400 mètres et - 10 °C : 4 300 mètres.

Situation en surface :

Zone dépressionnaire sur le Nord de l'Atlantique ; dépression principale, de valeur inférieure à 975 hPa, au voisinage des Iles Feroë, à laquelle est associée une perturbation à caractère de front froid ondulant, axée à 18 heures des Feroë au centre de la mer du Nord, à la Lorraine et au Lyonnais.

Le vol s'effectue d'abord à l'arrière de la perturbation, en secteur de traîne active s'atténuant vers Moulins, et à partir du Rhône en ciel de corps.

1.7.2. Conditions météorologiques sur la plaine de Valence et les contreforts du Vercors

Conditions sur l'ensemble de la zone :

Ciel couvert par altocumulus et altostratus en couches, bases 2 300 à 2 700 mètres, sommets s'étageant entre 3 500 et 5 500 mètres, doublés de 5 à 7/8 cumulus et stratocumulus, bases 600 à 800 mètres, sommets à 1 600/2 000 mètres (altitudes) ;

Visibilité : 5 à 10 km ;

Pluie faible intermittente ;

Au moment de l'accident les contreforts du Vercors sont probablement dans les nuages.

Temps sur l'aérodrome de Valence-Chabeuil au moment de l'accident :

Vent : secteur Nord/05 kt ;
Visibilité : 5 à 6 km (estimation) ;
Pluie ;
Nuages : 8/8 Sc à 600/750 m (estimation) ;
Température : + 9 °C ;
QNH : 1010 hPa, QFE : 991 hPa.

1.8. *Aides à la navigation aérienne*

Aucune anomalie de fonctionnement des aides à la navigation aérienne n'a été signalée ni constatée avant et après l'accident.

Dans les jours qui ont suivi l'accident, un contrôle en vol spécial a été effectué à la demande de la commission d'enquête par l'avion laboratoire du service technique de la navigation aérienne (S.T.N.A.). Ce contrôle en vol a eu pour but d'enregistrer et de vérifier les signaux émis par les différents moyens de radionavigation et d'atterrissage susceptibles d'avoir été utilisés par l'aéronef avant l'accident.

Lors de ce contrôle :

- le signal émis par le VOR VNE le long de la route spécifiée d'arrivée VNE-VE a été mesuré par l'avion laboratoire évoluant à 3 500 pieds QNH. Le signal enregistré sur ce parcours, à cette altitude, a été déclaré correct et exploitable à bord des aéronefs ;
- le signal émis par le VOR LSA le long de la trajectoire suivie par l'aéronef après son passage à la verticale de la balise VNE a été enregistré. Le signal émis par ce VOR, même s'il devient de plus en plus bruité au fur et à mesure que l'on se rapproche du lieu de l'accident, n'en fournit pas moins à bord une indication de position correcte.

Par la même occasion, l'exploitation de l'enregistreur de conversations dans le poste de pilotage indiquant que l'équipage avait cherché à utiliser le rayonnement résiduel arrière de l'ILS de Valence, la commission a demandé aux spécialistes de faire également des mesures sur ce rayonnement parasite. Le rayonnement arrière émis par le radioalignement de piste (RAP) de l'ILS de Valence a donc été enregistré le long de la trajectoire suivie par l'aéronef entre le VOR VNE et le lieu de l'accident.

Cet enregistrement montre que :

- durant la première moitié du parcours, l'indicateur de bord présente un drapeau d'alarme (déclarant les indications inutilisables) ;
- durant la seconde moitié du parcours, le drapeau d'alarme peut disparaître. Dans ce cas, l'aiguille verticale de l'indicateur de bord donne une indication.

Cette disparition du drapeau d'alarme dans une zone située en amont du réflecteur parabolique ILS est normale sur ce type d'ILS. car toute l'énergie émise n'est pas entièrement réfléchie par le réflecteur parabolique ILS. Une partie de l'énergie émise se propage vers l'arrière, pouvant même dans certaines directions fournir une indication d'axe stable.

Il faut rappeler qu'en France aucune procédure aux instruments n'est prévue ni possible avec usage du rayonnement arrière de l'ILS.

1.9. *Télécommunications*

1.9.1. Les communications radiotéléphoniques échangées entre le F-GGDM et les divers organismes de la circulation aérienne ont été normales et de bonne qualité à l'exception du premier contact avec le centre de contrôle régional de Marseille à 18 h 35 (voir transcription CVR). Le problème a été immédiatement réglé par changement de la fréquence affichée sur l'autre ensemble. Il semble en effet que les deux ensembles radio étaient calés sur la même fréquence, ce qui pouvait entraîner des perturbations.

A aucun moment l'équipage n'a signalé une quelconque difficulté aux organismes au sol.

1.9.2. La fréquence d'approche (125.7 MHz) de l'aérodrome de Valence est couplée à un radiogoniomètre dont l'indicateur est situé sur le pupitre du contrôleur.

En l'absence d'émission de la part de l'avion sur cette fréquence pendant les dernières minutes du vol, aucun relèvement n'a pu être effectué.

Toutefois, une vérification de cet équipement a été entreprise et a montré son bon fonctionnement.

1.9.3. L'avion était équipé d'une balise de détresse. Aucune réception de signal émis par cette balise n'a été signalée à l'heure de l'accident et pendant les heures qui ont suivi.

1.10. *Renseignements sur l'aérodrome*

L'aérodrome de Valence-Chabeuil est situé à environ 5 kilomètres dans l'Est de la ville de Valence et à une altitude de 162 mètres. Il est pourvu d'une piste en dur de 2 100 mètres de long, orientée 010°/190° ainsi que d'une piste non revêtue, réservée aux planeurs et aux avions légers.

Au plan des services de la circulation aérienne, l'aérodrome est doté d'un contrôle d'approche et d'un contrôle d'aérodrome. Il est pourvu d'une zone de contrôle (CTR) qui s'élève du sol à 300 mètres/sol. Cette CTR est surplombée par la partie C de la région terminale de contrôle (TMA) de Lyon dans laquelle le service du contrôle est également assuré par le contrôle d'approche de Valence jusqu'au niveau de vol 65.

Les altitudes minimales de sécurité, qui garantissent la marge de franchissement d'obstacles réglementaire dans les 25 milles nautiques autour de la balise VE ont pour valeurs : 5 100 pieds, 6 300 pieds et 9 200 pieds. A l'endroit de l'accident l'altitude de sécurité est de 9 200 pieds.

La trajectoire spécifiée d'arrivée que doivent suivre les aéronefs IFR en provenance du Nord-Ouest et à destination de Valence est, sauf instruction contraire des organismes du contrôle, la route VNE-VE Cette route correspond au radial 178° de VNE et est entièrement située en espace aérien contrôlé.

Sur cette trajectoire, les services du contrôle peuvent autoriser les aéronefs à descendre à 3 500 pieds QNH. Cette valeur assure entre VNE et VE - sur le radial 178° - la marge de franchissement d'obstacles réglementaire.

Trois procédures d'approche aux instruments entièrement situées en espace contrôlé sont publiées pour la piste 01 (donc face au Nord) de Valence : une procédure ILS, une procédure ILS sans radioalignement de descente et une procédure s'appuyant sur VE. Les atterrissages en piste 19 pour les vols IFR s'effectuent à l'issue de manœuvres à vue libres ou imposées après percée aux instruments sur l'axe radiobalisé 010°.

L'aérodrome de Valence n'est pas doté de station météorologique. La station météorologique la plus proche est celle de Montélimar.

Les renseignements météorologiques que doivent communiquer les organismes de la circulation aérienne aux pilotes pour effectuer les phases d'arrivée et de départ sont obtenus à Valence de la manière suivante :

- les pressions (QNH, QFE), la force et la direction du vent sont lues sur des appareils installés à la tour de contrôle (baromètres et déport à la tour des mesures de l'anémomètre) ;
- la mesure de visibilité résulte de l'observation depuis la tour de contrôle de repères caractéristiques (tour d'horizon) :
- les autres renseignements, en particulier le plafond, ne sont pas mesurés et peuvent simplement être estimés.

Les indicateurs de pression du type baromètre anéroïde en service à la tour de Valence au moment de l'accident présentaient depuis plusieurs mois des défauts de fiabilité, mais il a été vérifié que le jour de l'accident les valeurs données à l'équipage étaient correctes.

1.11. *Enregistreurs de bord*

Pour ce type d'aéronef, l'arrêté du 5 novembre 1987 relatif aux conditions d'utilisation des avions exploités par une entreprise de transport aérien rend obligatoire l'emport d'un enregistreur de conversations et d'alarmes sonores dans le poste de pilotage (CVR) et d'un enregistreur permettant la reconstitution de la trajectoire de l'avion (FDR).

Le FH 227 F-GGDM était donc équipé :

- d'un CVR Sundstrand V 557, numéro de série 1557 ;
- d'un FDR SFIM A 5610 S1, numéro de série 591 B.

Le FDR a été retrouvé le lendemain matin dans les débris de l'épave. Il avait été fortement endommagé par l'impact. Le boîtier électronique et le chargeur de bande photographique étaient désolidarisés. Cependant, malgré le délai de plus d'une heure imposé aux enquêteurs techniques avant qu'ils puissent accéder aux débris de l'appareil, la bande n'a pas été trop voilée par cette exposition prolongée à la lumière du jour et a pu être exploitée.

Le CVR s'était détaché de son support à l'impact et avait dévalé la pente. Il a été retrouvé environ 300 mètres plus bas. Il avait subi une très forte accélération longitudinale et plusieurs chocs violents ayant entraîné une importante déformation mécanique du boîtier extérieur et la destruction de toute la partie électronique qui n'est pas protégée.

Ce boîtier extérieur a dû être découpé à la cisaille. Le boîtier antichoc/antifeu a subi une déformation et la bande magnétique s'est repliée sur elle-même du fait de la forte décélération subie à l'impact. Elle présente de nombreuses pliures qui se sont malgré tout estompées après enroulement sur bobine et passage au lecteur. Le signal n'a pas subi de dégradation importante du fait de ces déformations.

Le développement de la bande FDR a permis de reconstituer la trajectoire air de l'avion (voir en annexe 5) et de la comparer avec la trajectoire radar. Selon cette reconstitution, l'impact a eu lieu au cap 173° à une vitesse de 187 kt et une altitude de 3 800 pieds au calage standard (1 013,25 hPa).

La transcription du CVR comprenant les conversations à l'intérieur du poste de pilotage, les communications radio entre aéronefs et organismes au sol et divers bruits figure en annexe.

Cette transcription a été très largement facilitée par le fait que les deux pilotes utilisaient leur équipement de tête (microcasque).

Les analyses spectrales effectuées sur la voie ambiance ainsi que les conversations entre pilotes permettent d'affirmer que les groupes motopropulseurs fonctionnaient.

1.12. *Renseignements sur l'épave et sur l'impact*

L'appareil s'est écrasé en ligne de vol sur une falaise située juste en dessous d'un point coté 1 308 mètres (La Croix de Tourniol) dans le 300° à 1 500 mètres du village de Léoncel.

Le point d'impact, au premier tiers inférieur de la falaise, est très nettement visible grâce aux traces de fumée laissées par la combustion du carburant au moment de l'impact.

Après le choc initial, les débris de l'appareil sont tombés dans la zone d'éboulis située au pied de la falaise. Cette zone d'éboulis présente une pente d'environ 40° et est couverte de cailloutis, d'herbe haute et de quelques arbustes qui ont arrêté les principaux éléments de l'appareil.

L'épave principale est constituée par une partie de l'arrière du fuselage comprenant le tiers inférieur de la dérive et de la gouverne de direction et par la majeure partie de l'aile gauche et du moteur gauche, le tout reposant sur le sol en position inverse.

L'enregistreur de paramètres a été retrouvé à cet endroit, encore en place dans la pointe arrière du fuselage.

A une vingtaine de mètres à l'Ouest, sur la même courbe de niveau, arrêtés par un arbuste, se trouvent la partie extrême de l'aile droite en position normale et quelques panneaux de la voilure centrale droite, avec en particulier le longeron arrière et les articulations de volet.

Entre la partie principale de l'épave et cet élément de l'aile droite on trouve, de l'Est vers l'Ouest, une quantité importante de petits débris, la majeure partie des sièges passagers, puis trois pales d'hélice et des panneaux de voilure.

En dessous de cette zone se trouvent quelques éléments de moteur dont un compresseur centrifuge, des panneaux de fuselage et des éléments de voilure de différentes longueurs (2 à 3 mètres).

Plus bas, à environ 10 mètres en dessous de l'épave principale, se trouvent une porte d'accès cabine et le carénage arrière d'une nacelle moteur.

A l'Est de l'épave principale, entre 0 et 30 mètres sur la même courbe de niveau, ont été retrouvés : une pale d'hélice, des éléments des glaces frontales du cockpit et un morceau de pédale de palonnier.

Toute cette zone est jonchée de petits débris difficilement identifiables compte tenu de leur fragmentation.

A 20 mètres environ en dessous de l'épave principale se trouvent de nombreux éléments des trains d'atterrissage, des régulateurs d'hélice, un alternateur et une bouteille d'oxygène. Dans l'Ouest, à 10 mètres et légèrement en dessous, se trouve la pointe arrière d'une nacelle moteur.

A 45 mètres en dessous de l'épave principale se trouve le plan fixe horizontal comportant encore un tiers de la dérive. Cette partie de dérive est fortement plissée. Une pale d'hélice pliée en deux est fichée dans le plan fixe. A la même hauteur, à 10 mètres à l'Est, se trouve un moyeu d'hélice sur lequel est encore fixée une pale.

Le CVR a été trouvé 10 mètres en dessous du plan fixe. Sur la même courbe de niveau se trouvaient le pneu de la roulette de nez, une porte d'issue de secours à 10 mètres environ vers l'Ouest puis divers éléments du régulateur de carburant, du relais d'accessoire, une génératrice démarreur et une articulation de contrefiche de train principal.

1.13. *Renseignements médicaux et pathologiques*

La commission a été informée des résultats des analyses toxicologiques effectuées dans le cadre de l'enquête judiciaire par l'institut de médecine légale de Grenoble. Ces examens effectués par chromatographie en phase gazeuse montrent l'absence de drogues psychotropes, de dérivés benzodiazépiniques ou cannabinoïdes dans le tissu musculaire des deux pilotes. Ils décèlent chez le copilote un taux d'alcool de 0,5 gramme par kilogramme.

Le résultat de l'analyse ne peut être contesté car aucune des causes pouvant le mettre en doute n'est reconnue :

- le corps n'a pas été carbonisé et n'a donc pas été soumis à une augmentation de température pouvant accélérer les phénomènes de fermentation cellulaire ;
- il n'y a pas eu d'inhalation de gaz toxiques avant la mort.

De plus, la *néogenèse d'alcool post mortem* est peu probable car le tissu musculaire du pilote, traité de la même manière, ne contient pas de traces d'alcool.

1.14. *Incendie*

A l'impact, le carburant contenu dans les différents réservoirs s'est répandu sur la paroi rocheuse et a pris feu, ainsi qu'en témoignent les traces de suie noire laissées sur la falaise. La combustion a donc été localisée principalement sur la paroi, quelques débris de l'épave, en particulier l'aile gauche et le moteur gauche, ont continué à brûler en arrivant sur la zone d'éboulis.

1.15. *Questions relatives à la survie des occupants*

Le dernier contact radio a eu lieu à 19 h 05 avec les opérations de la Compagnie E.A.S. à Valence. Le copilote prévoyait la verticale du terrain à 19 h 10 et l'atterrissage à 19 h 15.

A 19 h 35, la phase de détresse a été déclenchée. La zone initiale de recherche comprenait les départements de la Drôme, de l'Isère, du Rhône et de l'Ardèche.

A 21 heures, l'exploitation des enregistrements radar a conduit à définir une zone de recherche plus réduite, située entre les villages de Peyrus et Léoncel.

Le premier témoignage recueilli à 21 h 39 a permis de centrer les recherches sur le col de Tourniol.

L'épave a été découverte à 23 h 20.

Compte tenu de la violence de l'impact, l'accident ne laissait aucune possibilité de survie aux occupants de l'avion.

2. ANALYSE

2.1. *Déroulement du vol*

Jusqu'au passage du VOR de Vienne, le vol se déroule normalement en apparence. L'équipage est détendu, il plaisante et ne fait état d'aucun problème particulier. La répartition des tâches est la suivante : le commandant de bord est aux commandes, le copilote assure les communications, procède aux affichages de fréquence et aux calculs d'estimées.

A 18 h 35, le contrôleur de Marseille signale un problème de réception (voix chevrotante) qui disparaît rapidement, après un changement de fréquence sur la seconde VHF. Après une tentative infructueuse de contact avec l'escale d'EAS à Valence, un contact préliminaire avec l'approche de Valence permet au copilote d'obtenir les renseignements météorologiques mesurés ou estimés sur l'aéroport de destination.

Peu avant LESPI (18 h 44), le commandant de bord demande l'affichage de Vienne (VOR VNE) sur son récepteur VOR, et de 114.75 (fréquence correspondant au VOR/DME LSA) avec le radial 178 sur celui du copilote. Cette dernière indication est surprenante, car 178 correspond à la route à prendre de VNE pour se diriger vers Valence. Il convient de noter que l'indicatif LSA ne sera prononcé par aucun des deux hommes à cette occasion. Par contre, trois minutes plus tôt, à 18 h 41, le copilote avait annoncé avoir sélectionné LSA et 112.7 Montélimar sur le 2. Il s'agissait vraisemblablement des fréquences DME. C'est ici que se situe la première source d'erreur possible.

A 18 h 47, le copilote indique que le passage de Vienne devrait se faire à 18 h 57. A 18 h 49, la descente commence. On constate à cette occasion une augmentation de la vitesse de l'avion, qui passe de 187 à 225 kt.

Entre 18 h 54 et 18 h 55, moins d'une minute avant l'arrivée sur VNE, l'équipage identifie avec précision des repères au sol.

Juste avant le passage de VNE, le contrôleur de Lyon-Satolas signale à l'équipage : « *G.A.*, vous arrivez sur Vienne - à droite sur VE au 60. » Le pilote prend alors un cap Sud puis annonce : « Voilà 178 dans un premier temps... 114.75. » Il y a tout lieu de penser qu'il affiche lui-même sur son indicateur le radial 178 et sur son récepteur VOR la fréquence 114.75. Le copilote lui dit d'ailleurs en plaisantant qu'il l'aurait fait pour lui, considérant que c'est son travail. Quoi qu'il en soit, LSA VOR est identifié. C'est à ce stade que se situe l'erreur fondamentale conduisant à la catastrophe. La commission a retenu trois hypothèses pour cette erreur :

1. Affichage du bon radial matérialisant la route à suivre à partir de VNE, avec affichage voulu provisoire puis oublié de la fréquence 114,75 (LSA). Ce processus est nécessaire si l'on veut recevoir le DME LSA compte tenu de l'installation de bord (commandes récepteurs et indicateurs des moyens de radio-navigation).
2. Affichage de la fréquence de LSA au lieu de celle de VNE.
3. Erreur sur la trajectoire à suivre : le 178 de LSA (au lieu de VNE).

Les conditions dans lesquelles se passent la sélection et la vérification du VOR ne permettent pas de lever le doute mais peuvent permettre en revanche de mieux comprendre que l'équipage ne se rende pas compte de l'erreur commise.

Il est clair qu'à partir de ce moment, le pilote utilise le 178 de LSA pour se diriger vers Valence et qu'il prend des caps pour rejoindre ce radial. Il ne semble pas y avoir eu ensuite pendant plusieurs minutes de la part de l'un ou l'autre pilote un lever de doute à partir d'une représentation mentale même sommaire, par exemple écart entre route à suivre et cap - ou par une utilisation rationnelle des autres informations radioélectriques.

Le copilote reprend le réglage des radiocompas puis affiche l'ILS de Valence sur son récepteur à la demande du commandant de bord. Il est 19 h 01 mn 30 s et le commandant de bord annonce : « Je suis sur l'axe donc... et plus de problème ». Ils font les vérifications d'approche. A partir de 19 h 02 mn 31 s, le commandant de bord commence à s'inquiéter des indications de son radio-compas qui lui paraissent incohérentes avec ce qu'il croit être sa position. Le copilote déclare que ses indications sont bonnes et lui en transfère l'affichage sans doute par le positionnement de la clé de l'indicateur du commandant de bord (aiguille n° 2 sur ADF).

Le commandant de bord observer toujours avec surprise que l'instrument indique 30 degrés d'écart mais l'interception du radial 178 le rassure. Pour un pilote, une information VHF est toujours plus crédible qu'une information MF, surtout de nuit. Il demande alors l'affichage de l'ILS sur son récepteur et affiche ou fait afficher le QFU inverse sur son indicateur. Le copilote entre ensuite en contact radio avec l'escale. A 19 h 06 mn 15 s, le commandant de bord s'inquiète à nouveau de l'indication du radio-compas.

A 19 h 07 mn 02 s, malgré une vérification de distance avec le DME de Montélimar (MTL) qui trouble les deux pilotes, le commandant de bord semble cependant se conforter dans sa certitude d'être sur la bonne route par une utilisation malencontreuse de l'ILS dans un secteur où ses indications étaient inutilisables. C'est dans ces conditions que l'avion percute la falaise.

2.2. *Autres éléments d'analyse*

A partir de l'erreur initiale, l'analyse des actions de l'équipage fait apparaître un manque d'esprit critique au niveau de chacun des pilotes ainsi qu'un contrôle mutuel insuffisant dans le cadre de la répartition des tâches. Ce cadre est lui-même peu défini par l'exploitant. En outre, le contact radio avec les opérations EAS de Valence a eu lieu dans une phase de vol où la disponibilité du copilote eût été plus utile pour le suivi de la navigation que pour des considérations d'ordre commercial.

Il est possible que l'équipage qui avait prévu de passer le VOR VNE à 57 (soit 2 minutes plus tard) se soit cru plus à l'Ouest de la route, pensant avoir viré avant la verticale. Ceci rendait plausible la nécessité d'une altération de cap plus longue pour rejoindre le radial 178. La phraséologie du contrôleur « Vous arrivez sur Vienne » a pu entretenir cette ambiguïté.

Les indications météorologiques approximatives obtenues du fait de l'insuffisance des moyens à Valence ont pu conduire l'équipage qui avait connaissance de cette situation à repousser au dernier moment sa prise de décision quant au type d'approche finale à effectuer.

La disposition des commandes et des indications sur la planche de bord de même que des moyens d'affichage n'était pas identique sur les quatre avions du secteur F 27 de la Compagnie. Ces différences ont pu entraîner des hésitations et de mauvaises interprétations de la part de l'équipage.

De plus, l'équipement de radionavigation de bord, aboutissement de modifications successives au cours de la vie de cet avion, donnait un ensemble hétéroclite, propice aux erreurs d'affichage et d'interprétation.

Les noms de lieu associés aux moyens de radionavigation dans les cartes d'arrivée aux instruments Jeppesen utilisées par l'équipage pouvaient être source de confusion. En effet, le VOR VNE est appelé « Lyon-Satolas » et le VOR LSA « Lyon ».

L'association de ces noms aux indicatifs codés pourrait provenir de la présentation ambiguë du Manuel d'Informations Aéronautiques français. En effet, dans la liste des aides radio associées à l'aérodrome de Lyon-Satolas figurent les VOR

« VNE et LSA » sans qu'une dénomination en clair leur soit donnée.

La répartition des tâches du service du contrôle d'approche entre les approches de Lyon et de Valence, en vigueur au moment de l'accident, n'a pas permis d'utiliser de manière optimale la couverture radar existante.

Le contrôleur de Valence ne disposant pas d'image radar ne pouvait détecter au goniomètre l'erreur de navigation en l'absence d'appel radio de l'avion.

Enfin, la commission s'est interrogée sur le rôle qu'à pu jouer le taux d'alcoolémie du copilote car celui-ci procédait aux vérifications des instruments. Sachant que le taux d'alcool trouvé dans les tissus (ici 0,5 g) est équivalent ou légèrement inférieur à celui qui se trouve dans le sang et sachant que l'alcoolémie décroît d'environ 0,16 gramme par heure, on peut estimer qu'il avait au début du vol une alcoolémie voisine de 0,7 gramme.

Cette dose est suffisante pour créer une dégradation des performances chez un sujet devant exécuter simultanément plusieurs tâches. Des études réalisées aux Etats-Unis démontrent nettement qu'une alcoolémie de 0,4 gramme est capable d'entraîner une détérioration dangereuse des facultés d'accomplissement des manœuvres de pilotage, et cela d'autant plus que le rythme des opérations est accéléré.

3. CONCLUSIONS

3.1. *Faits établis par l'enquête*

L'aéronef était certifié et entretenu conformément à la réglementation en vigueur.

La masse et le centrage n'ont pas joué de rôle dans l'accident.

Aucun défaut significatif de fonctionnement de l'avion ou de ses équipements n'a été mis en évidence.

L'équipage détenait les brevets, licences et qualifications réglementairement nécessaires à l'accomplissement du vol.

Les aides à la navigation aérienne fonctionnaient normalement.

Les organismes de la circulation aérienne ont fourni les services du contrôle et d'information de vol conformément aux règlements et consignes en vigueur.

Le vol se déroulait de nuit. Au moment de l'accident, l'équipage n'avait pas la vision du sol.

Le copilote présentait une alcoolémie modérée.

Après le passage de Vienne, l'avion devait suivre le radial 178 du VOR VNE.

L'équipage a affiché le VOR LSA et s'est dirigé sur le radial 178 de ce VOR.

L'équipage n'a pas tenu compte des indications des radiocompas.

Dans la phase finale du vol, l'équipage a affiché l'ILS de Valence. Il en a, semble-t-il, utilisé le rayonnement arrière.

Le contrôle de l'avion a été transféré par l'approche de Lyon à l'approche de Valence conformément aux consignes en vigueur.

La couverture radar disponible permettait de suivre la trajectoire de l'avion. Cependant seule l'approche de Lyon dispose d'une visualisation des images radar.

Dans les dernières minutes du vol, l'absence d'émission de l'avion sur la fréquence d'approche de Valence n'a pas permis l'affichage d'une indication radiogoniométrique.

L'avion a heurté le relief à dix milles nautiques à l'Est de la route qu'il devait obligatoirement suivre, compte tenu de son altitude de vol.

3.2. *Causes probables de l'accident*

L'accident résulte directement d'une erreur de navigation.

Cette erreur a pour causes directes :

- l'affichage et l'utilisation du VOR LSA au lieu de VNE ;
- une insuffisance de la représentation mentale de la trajectoire de l'avion à partir des autres informations disponibles.

En outre, le manque de rigueur dans le partage des tâches, dans leur exécution ainsi que dans le contrôle mutuel sont des facteurs contributifs.

La commission a également noté que les faits suivants ont pu faciliter la genèse d'une situation critique :

- la documentation de navigation qu'utilisait l'équipage et l'organisation du tableau de bord de l'avion pouvaient être sources d'erreurs ;
- l'organisation de l'espace aérien dans la région de Valence ne permettait pas une utilisation optimale des moyens radar existants ;
- les tâches de l'équipage étaient peu définies par l'exploitant ;
- le copilote présentait une alcoolémie modérée mais significative.

4. RECOMMANDATIONS

4.1. *Formation des équipages*

L'enquête ayant mis en évidence une erreur de navigation, la commission s'est interrogée sur le comportement de l'équipage et les différents facteurs qui ont pu l'amener à commettre cette erreur.

L'interrogation principale porte sur la non-détection de cette erreur de trajectoire et sur la matérialisation permanente de la position de l'avion dans l'espace. Par ailleurs, la commission a noté de graves insuffisances dans :

- le contrôle de la trajectoire par chacun des pilotes ;
- le contrôle croisé des actions effectuées ;
- l'organisation du travail à bord et la répartition des tâches.

Il n'est pas possible d'affirmer que ce type de comportement est tout à fait exceptionnel. Cela pose donc le problème de la formation pratique de base, du niveau de qualification et du maintien des compétences des équipages de transport aérien.

4.1.1. *Formation de base*

En ce qui concerne la formation de base, la commission d'enquête recommande :

- que l'accent soit mis sur la représentation mentale permanente de la position de l'aéronef dans l'espace et sur l'aptitude à un haut niveau de charge de travail en gardant une disponibilité suffisante. Ces acquis doivent permettre aux pilotes de conserver ultérieurement au cours de leur carrière des comportements réflexes d'analyse rapide des informations.

Ensuite, s'appuyant sur cette formation de base, viendront se greffer les applications en ligne incluant une bonne répartition des tâches tout en conservant un engagement responsable et systématique des deux pilotes par rapport à la trajectoire de l'aéronef, quelle que soit leur fonction à bord.

4.1.2. Qualification de type

Lors de la qualification d'un membre d'équipage de conduite sur un nouveau type d'aéronef, la commission rappelle que la *formation correspondante doit comprendre non seulement* un enseignement de base à caractère documentaire et descriptif de la nouvelle machine mais aussi une formation en vol. Cette formation pratique doit comporter l'utilisation en condition de vol aux instruments et notamment assurer la connaissance précise des performances, des caractéristiques et des équipements de l'appareil.

Dans le cas d'aéronefs de même « famille », couverts par la même qualification officielle, la commission d'enquête recommande :

- qu'une attention particulière soit portée à la qualification des pilotes en insistant particulièrement sur les différences de définition et d'équipements.

4.1.3. Maintien du niveau de compétence

Il serait illusoire de penser qu'un diplôme puisse garantir à lui seul une compétence suffisante dans les divers domaines d'exploitation pour la durée d'une carrière. Un apport substantiel et permanent doit donc être fourni par les exploitants grâce à un encadrement de qualité.

La commission d'enquête recommande :

- que l'attention des exploitants soit attirée sur leur responsabilité dans l'acquisition et le maintien du niveau de compétence de leur personnel navigant (compétence ayant ici un sens différent et plus exigeant que les « privilèges » conférés par l'obtention des diplômes d'Etat).

Cette exigence nécessite que l'exploitant dispose d'une structure d'instruction suffisante ou, dans le cas contraire, utilise les centres d'instruction ou les services d'autres compagnies.

La commission d'enquête recommande :

- que les exploitants ayant une structure de formation insuffisante soient invités à utiliser les centres et moyens de formation extérieurs disponibles.

4.1.4. Méthode de travail à bord

La commission d'enquête recommande :

- qu'une méthode rigoureuse de travail à bord comportant une répartition des tâches avec vérifications croisées des actions soit généralisée et respectée rigoureusement dans le cadre des consignes opérationnelles des compagnies.

L'application effective de cette méthode de travail en équipage devrait faire l'objet de tous les soins du chef pilote et de l'encadrement afin de lutter contre les dérives pouvant résulter de la routine.

4.2. *Analyse des vols*

A l'occasion de cet accident, la commission a été amenée à constater l'extrême importance de la mise en œuvre, à des fins tant correctives que préventives, d'une analyse des vols basée sur tous les éléments disponibles, y compris les enregistreurs de vol. Un tel type d'analyse des vols n'est actuellement exigé réglementairement que pour les avions de plus de 40 tonnes exploités en équipage à deux.

La commission recommande :

- que l'obligation réglementaire d'une telle analyse des vols soit étendue aux avions d'une masse maximale certifiée au décollage de plus de 20 tonnes et pour tous les avions à réaction.

4.3. *Affrètements*

La commission estime que, dans le cas d'un affrètement, l'affréteur, qui fournit son « label » et donc bénéficie de la confiance des passagers, ne peut se désintéresser de la capacité technique de la compagnie affrétée d'assurer le type de service attendu.

Certes, la compagnie affrétée doit elle-même avoir reçu les autorisations nécessaires pour effectuer du transport public. Cependant, dans une phase de création ou de croissance rapide de certaines petites compagnies aériennes, ces dernières peuvent avoir de la difficulté à évaluer certains problèmes techniques tels que le contrôle de la machine, de ses équipements ou de la compétence des équipages.

Si, en elle-même, la procédure de l'affrètement, largement employée actuellement, ne constitue pas un risque pour la sécurité aérienne, l'existence d'une garantie normale de l'affréteur vis-à-vis du public lui impose de prendre un minimum d'assurances sur le niveau technique du couple machine-équipage affrété.

La commission recommande en conséquence :

- qu'un texte réglementaire délimite précisément les obligations de chacune des compagnies affréteuse et affrétée.

4.4. *Equipements de bord*

4.4.1. Il est important qu'une « planche de bord » ne soit pas « bricolée » par adjonctions successives d'éléments, sans que ceux-ci s'intègrent dans une conception d'ensemble de nature à éviter les confusions.

La commission recommande :

- qu'une étude soit réalisée en vue d'amener les exploitants à une meilleure standardisation dans les équipements de pilotage et de navigation et dans la disposition des planches de bord de leurs avions de même type ou de types voisins.

Dans le but d'éliminer autant que possible tout ce qui peut porter en germe un risque de confusion, la commission tient à souligner l'intérêt du montage de dispositifs permettant d'afficher automatiquement sur le tableau de bord l'indicatif de l'équipement radioélectrique qui émet sur la fréquence effectivement reçue (décodeurs automatiques d'indicatif).

4.4.2. Dans certaines circonstances, le pilote automatique est un équipement essentiel pour l'amélioration de la disponibilité de l'équipage qui peut ainsi se concentrer davantage sur les fonctions décisionnelles primordiales.

La commission recommande :

- que, sur avion exploité en transport public, le montage d'un dispositif de pilotage automatique soit rendu obligatoire.

4.5. *Utilisation des ILS*

A l'occasion de l'examen approfondi de la bande d'enregistrement des conversations et de la reconstitution des dernières phases du vol, la commission a acquis la conviction que la tentation de l'équipage a été très forte, s'il n'y a cédé, d'utiliser le faisceau arrière de l'ILS de Valence comme aide de guidage d'axe afin de survoler les installations de l'aéroport cap au Sud et d'effectuer ensuite, en fonction des conditions météorologiques réellement rencontrées, un retour sur l'axe d'atterrissage en service face au Nord.

En France, aucune procédure officielle n'est basée sur ce rayonnement qui peut être considéré comme parasite et qui n'est d'ailleurs aucunement contrôlé, même si parfois, et le phénomène n'en est que plus dangereux, certains rayonnements secondaires peuvent donner une impression d'axe stable.

La commission recommande en conséquence (*) :

- que, par tous moyens de diffusion aux équipages, il soit bien rappelé qu'en aucun cas ce rayonnement arrière, variable et irrégulier suivant les installations, ne peut et ne doit être utilisé pour fournir un guidage.

4.6. *Aspects médicaux*

Les constatations faites à l'occasion de cet accident amènent la commission à rappeler que l'aptitude physique des navigants et leurs pratiques alimentaires (y compris en matière d'alcoolémie) doivent faire l'objet de rappels fréquents et d'un suivi médical approprié.

La commission recommande :

- qu'une action de sensibilisation soit entreprise auprès des compagnies pour que tous les navigants soient avertis des risques graves que peut entraîner la consommation de boissons alcoolisées même si l'alcoolémie qui en résulte peut paraître minime et sans conséquence dans les circonstances de la vie courante.

Elle préconise qu'une législation soit élaborée pour fixer un taux d'alcoolémie maximum au-delà duquel tout vol serait interdit, quelle que soit la fonction exercée au sein de l'équipage. Compte tenu de la faiblesse du taux limite qui serait fixé, les règlements devraient préciser les modalités d'analyse à employer pour l'application de ces dispositions.

4.7. *Service de la navigation aérienne*

4.7.1. Utilisation optimale des moyens radar

La commission recommande :

- que, sans modifier en particulier les dispositions d'application mondiale qui conditionnent le fonctionnement du contrôle de la circulation aérienne civile et les responsabilités juridiques respectives qui en découlent pour le commandant de bord et pour le contrôleur de la circulation aérienne, la couverture radar disponible soit employée au mieux, là où elle existe, pour les fins du contrôle de la circulation aérienne.

Ceci peut entraîner une extension de certains espaces aériens de façon à englober de nouvelles portions de trajectoires ou une nouvelle définition de la limite entre deux espaces aériens contigus. Ces révisions auraient essentiellement pour effet de faciliter la détection par le contrôleur, dans le cas où sa charge de travail réglementaire qui consiste à séparer les avions entre eux le lui permettrait, d'une anomalie grave dans le comporte-

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(*) Compte tenu de l'urgence, par lettre du 13 juillet 1989, la commission d'enquête avait transmis cette recommandation à la direction générale de l'aviation civile. Une circulaire d'information aéronautique, série A, n° 6, du 14 décembre 1989 a été publiée pour attirer l'attention des usagers en leur rappelant qu'il est dangereux de vouloir utiliser les rayonnements arrière des ILS.

ment d'un appareil et de tenter d'intervenir à temps de façon à porter assistance à des personnes qu'il est possible de présumer en péril.

4.7.2. Dispositif d'alerte de proximité du sol

La commission recommande :

- que, de même qu'en matière de contrôle de la circulation aérienne un « filet de sauvegarde » a été mis en œuvre, soient poursuivies et encouragées les études et recherches aux fins de mettre au point un dispositif automatique d'alerte des contrôleurs, lorsque la hauteur de l'avion au-dessus du sol environnant, dans une zone à définir, tombe au-dessous d'une certaine valeur.

4.7.3. Publications aéronautiques

La commission recommande :

- que soient évitées dans les publications aéronautiques toutes possibilités de confusion entre le nom d'une aide radio-électrique, son indicatif et son site géographique qui doivent autant que possible pouvoir être corrélés sous une dénomination simple.

Il serait de même souhaitable d'éviter d'utiliser dans la même zone des indicatifs trop voisins.

Cette recommandation vise à permettre une corrélation intellectuelle dénuée d'ambiguïté et à faciliter ainsi la tâche de préparation du vol, les tâches de navigation à bord, ainsi qu'à préciser les échanges radio entre l'équipage et le personnel au sol.

4.7.4. Informations météorologiques

Il est important que, par quelque moyen que ce soit, pourvu qu'il soit fiable et de qualité, le pilote dispose tant d'une prévision d'atterrissage valable que d'une observation précise du temps présent.

S'il n'est pas possible de disposer de personnel météorologique spécialisé, il est indispensable que le personnel du contrôle dispose d'équipements installés dans la tour de contrôle lui permettant de fournir à l'équipage les paramètres météorologiques nécessaires.

La commission recommande :

- qu'une attention persistante soit apportée à la fourniture des informations météorologiques nécessaires au pilote pour décider des conditions de son approche sur un aérodrome.

4.8. *Devis de masse et de centrage*

Après avoir constaté qu'il ne lui a pas été possible de disposer du devis de masse et de centrage, détruit dans l'accident, la commission recommande :

- que la réglementation relative à ce document soit rappelée, à savoir qu'un exemplaire du devis de masse et de centrage doit rester disponible au sol, de façon à être utilisable pour toute recherche.

5. APPROBATION DU RAPPORT

Le présent rapport a été adopté à l'unanimité par les membres de la commission d'enquête le 4 mai 1990.

ICAO Ref.: 061/89

No. 4

McDonnell-Douglas DC-8-62, N1809E, accident near Paramaribo/Zanderij International Airport, Suriname on 7 June 1989. Report released by the Commission of Inquiry, Suriname

1. INTRODUCTION

On 7 June 1989 a DC8-62 crashed near Zanderij International, in the Para district. Additional details:

Airline:	Surinaamse Luchtvaart Maatschappij NV (SLM) (Suriname Airways Limited)
Manufacturer:	McDonnell Douglas
Model:	DC8-62
State of Registry:	USA
Registration:	N1809E
Serial no.:	46107
Owner:	Suriname Airways Holding Company
Place:	Near Zanderij Airport, Para District
Date:	Wednesday 7 June 1989
Time:	*About 04:27 local time (07.27 UTC)*

2. OVERVIEW

A DC8-62 on a non-stop SLM flight (PY764) from Amsterdam/Schiphol crashed during the approach. There were 187 persons aboard:

3 cockpit crew

6 cabin crew

178 passengers, including an off-duty flight engineer.

A corpse was also being transported.

The aircraft was totally destroyed when it struck the ground. There was a postcrash fire which was extinguished by the fire department.

The Director of the Department of Aviation was notified about the accident in accordance with prescribed procedures. The Department of Aviation notified all involved authorities.

As the aircraft was of American registry, the Federal Aviation Administration (FAA) and the National Transportation Safety Board (NTSB) were notified immediately in accordance with Annex 13 (Accident Investigation) of the Chicago Convention.

The Department of Aviation began its preliminary investigation immediately with the gathering of all relevant data. Following the rescue and recovery activities priority was given to the retrieval of the Cockpit Voice Recorder and the Flight Data Recorder. These devices contain vital information about the operation of the flight; on 8 June 1989 they were shipped to the main office of the NTSB in Washington, D.C., for processing.

The Director of the Department of Aviation requested and obtained assistance from the NTSB and the FAA in accordance with the provision in Annex 13 of the Chicago Convention.

The preliminary investigation focused on the following areas:

- Operational aspects
- Human Factors

- Structures, powerplants, systems and maintenance
- Meteorological aspects

The preliminary investigation also involved work at the accident scene, various hearings and the testing of navigational aids.

The information available at the conclusion of the work at the scene and the necessary hearings led to the preliminary conclusion that the immediate cause of the accident might possibly be pilot error.

The preliminary investigation was concluded on 14 June 1989. All the assembled information was made available to the Commission of Inquiry which, in the meantime, had been established by the Attorney General by Order no. 3441 of 8 June 1989.

The Commission was established in accordance with Articles 42 and 43 of the Regulations for State Control of Aviation (G.B. 1939 no. 33, G.B. 1955 no. 70, as revised by S.B. 1984 no. 115) in order to "provide information and report on the probable cause" of the afore-mentioned accident as prescribed by law.

3. FACTUAL INFORMATION

3.1 History of the Flight

The Captain and his two crew members arrived in Amsterdam on Saturday 3 June 1989. The flight departed Amsterdam/Schiphol on 6 June 1989 at 23.25 local time (2225 UTC) and proceeded non-stop to Paramaribo with an estimated time of arrival of 04.27 local time (0727 UTC).

Preparations for the flight in Amsterdam were normal. According to survivors the flight was rather smooth. About 20 minutes before arrival in Paramaribo the crew received the 0700 UTC weather for Zanderij: "Wind calm","visibility 900 m in fog", "temperature/ dewpoint 22°C/22°C". The tower at Zanderij Airport cleared the flight for a VOR/DME approach to runway 10.

However, this aircraft crashed near the Zanderij Airport at about 04.27 local time on 7 June 1989, during the hours of darkness. The weather at the time of the accident: horizontal visibility 900 m, with fog, and a cloud base of about 400 feet above the ground.

Shortly after the accident the visibility decreased to about 500 m; one hour after the accident it went down to about 200 m. The aircraft struck the ground about 2800 m from the threshold of runway 10. The wreckage came to rest a few meters north of the extended centerline of runway 10.

The aircraft logbook was not recovered. During the examination of the wreckage it was determined that the right wing fuel tank was intact and still contained fuel. Calculations showed that the aircraft's fuel load was between 16000 and 22000 lbs at the time of the accident.

3.2 Injuries to Persons

Injuries	Crew	Passengers	Total
Fatal	9	169	178
Serious	-	7	7
Minor/None	-	2	2
Total	9	178	187

One child was unhurt. Of the 15 persons that were rescued, 7 (seven) died later.

3.3 Damage to Airplane

The on-the-scene investigation revealed that engine no. 2 struck a tree about 25 m above the ground and about 300 m from the runway. The tree had a height of about 32 m

This impact resulted in the separation of a large part of the engine cowling, the fan section, and part of the low pressure compressor. The next impact involved the right wing which struck another tree.

The aircraft rolled around its longitudinal axis, struck the ground inverted, and broke up. The fire that erupted consumed portions of the airplane. The airplane was totally destroyed.

3.4 Other Damage

There were no reports of damage to the property of third parties on the ground.

3.5 Personnel Information

3.5.1 Cockpit Crew

The cockpit crew consisted of a pilot-in-command, a first officer, and a flight engineer.

The crew was hired on the basis of a contract.

with Air Crew International (ACI) in Florida.

The contract stipulated that ACI would furnish SLM with qualified crew members who held FAA certificates and who met the regulatory requirements to fly the DC8. It should be noted that ACI did not provide for proficiency checks but left it to the individual pilots to meet the training and other requirements of their profession. Examination of the captain's qualifications disclosed that he completed his last proficiency check on 16 April 1989 in a small twin-engine airplane (Grumman Cougar GA-7) instead of in a DC8, as required. The captain's age was 66. Additional information about this crew follows:

3.5.1.1. Captain:

Date of birth:	31 January 1923
Place of birth:	Kinderhook, Pennsylvania
Nationality:	USA
Certificate:	Airline Transport Pilot
Last Medical Exam:	11 January 1989, Class I
Ratings:	Multi-engine, Turbojet, DC8, B747
Proficiency Check:	16 April 1989 on a GA-7 belonging to Flying Tigers, Inc.
Logbook:	Not found
Flight time DC8:	About 8800 hrs
Total time:	19450 hrs
Last Route Check:	Miami-Zanderij via Port au Prince on 4-1-1989

History of Tests

ATP:	Applied for test on 12 October 1970. The flight test was unsatisfactory with regard to the ILS approach procedure and judgement. An FAA inspector was the examiner and failed the applicant. The re-testing on 30 October 1970 was satisfactory.
DC8:	Applied for test on 30 May 1973. The applicant failed the test on 7 June 1973 because of an unsatisfactory pre-flight inspection and flight test. The examiner: FAA inspector Applied for a re-test on 14 June 1973. Failed again on 15 June 1973 due to unsatisfactory results in the following areas: Takeoff, simulated engine failure, holding, instrument approaches, steep turns. Applied for a re-test on 21 June 1973. Type rating issued on 5 July 1973 (FAA inspector.
Type Rating B747	Applicant failed the test on 30 December 1985. Re-tested and failed by FAA inspector due to unsatisfactory results in the following areas: holding, missed approach, and landing. Again applied for test on 8 January 1986. He passed the test on 8 January 1986 with the same examiner.

Since 1985, the Captain was associated with Air Crew International, Inc.

Medical Factors:	The FAA provided details about the medical examinations. He always passed these examinations. His most recent medical certificate is dated 11 January 1989 with the notation: "Holder shall possess correcting glasses for near vision while exercising the privileges of his airman certificate."

3.5.1.2 First Officer

The correct identity and, therefore, the privileges of the first officer could not be clearly established from the information obtained from the American Department of Transportation and the British Civil Aviation Authority.

The following information was obtained from his most recent FAA certificate no. 226500, dated 23 February 1982.

Date of birth:	1 July 1954
Place of birth:	Fort Worth, Texas
Certificate:	ATP
Last Medical Exam.:	12 January 1989
Ratings:	Multi-engine, Turbojet, B737, SD330, Flight instructor.
Proficiency Check:	26 June 1988 on a DC-8
Logbook:	Not found
Flight time DC8:	Unknown

Total time: About 6600 hrs.

Last known route check: Zanderij-Belem via Cayenne on 15 December 1988.

Background

After flying for several companies, the first officer began to work for Air Crew International, Inc., in December 1988.

During the review of his certifcation it became apparent from the information obtained from England (CAA) and the USA (FAA) that this pilot had several identities and that his first American certificate was issued by the FAA on the basis of "UK license no.84846". Apparently, he was known for some time as born on 1 July 1945 in Newport, South Wales, England; next as born on 5 September 1946 in Kenilworth, Coventry, England; and finally as born on 1 July 1954 in Texas, USA.

However, the British Civil Aviation Authority stated that said a.k.a. never possessed a British pilot certificate.

The First officer pilot privileges were suspended following and aircraft accident near Wichita Falls, Kansas, USA.

Medical Factors

Medical information from the FAA indicates that the first officer met the medical requirements. His most recent medical certificate was dated 12 January 1989.

3.5.1.3 Flight Engineer

Date and place of birth: 2 April 1924, in Ada, Oklahoma
Certificate: Flight engineer and mechanic certificate
Medical exam.: 4 May 1989 (USA)
Ratings: DC6; DC10; B727; DC8
Proficiency Check: Unknown
Logbook: Not found
DC8 time: About 720 hrs.
Total time: About 26600 hrs
Route check: Miami-Zanderij via Port au Prince on 14 January 1989

Medical Factors

The available medical data indicate that the flight engineer met the medical requirements. His most recent medical certificate is dated 4 May 1989.

Cabin Crew

There were 6 cabin crew aboard the aircraft.

3.6 Airplane Information

The airplane was a Douglas DC8-62, fuselage no. 498, serial no. 46107 and American registration N1809E.

The Douglas Aircraft Company delivered the airplane to Braniff International Airways on 17 November 1969. On 17 November 1981 the airplane was returned to Douglas where it was stored until it was sold to the Arrow Air, Inc. on 21 December 1983.

SLM operated the airplane from 23 January 1986 till 15 July 1987, when Tropical Airways, Inc., became the operator, until 2 August 1987 From 2 August 1987, SLM was the only operator of the airplane.

The registration of the airplane, N1809E has never been changed.

The engines were fitted with hush-kits. The airplane had accumulated over 52706 hrs and 20342 cycles. It is interesting to note that the airplane was equipped with a Sundstrand Mark I Ground Proximity Warning computer, P/N965-0376-071, which gave audible warnings that were recorded by the CVR. In addition, this airplane had the following navigational aids:

- dual INS (Inertial Navigation System)
- dual Omega/VLF
- dual VOR/ILS/DME
- dual NDB receivers
- dual Marker receivers
- dual Radio altimeters

The airplane was owned by Surinam Airways Holding Company. It became operational again on 25 May 1989 after undergoing a "C" check; this maintenance was performed by CargoLux in Luxemburg.

The maintenance documents indicated that all Service Bulletins and Airworthiness Directives were complied with and that the airplane was airworthy.

3.7 Meteorological Information

At the time of the accident the horizontal visibility was 900 m in fog, 2/8 cloud cover, fog, with a cloud base of about 400 ft, wind calm, temperature/dewpoint 22°C/22°C and a pressure of 1012 millibars (mb).

This information was provided to PY764 by the Tower. Shortly after the accident the visibility descreased to 500 m and within one hour after the accident the visibility further decreased to 200 m.

The weather at Zanderij Airport between 0300 and 0500 can be summarized as follows:

Time(local)	0300	0400	0410	0430	0440	0500
wind	calm	calm	-	-	-	calm
Hor.Vis.	6000 m	900 m	900 m	500 m	200 m	800 m
Weather	fog	fog	-	-	-	fog
Clouds	1ST 120m	2ST 120m	-	-	-	1St 400f
Rel.Hum.	97%	97%	-	-	-	97%
Temp. Dew Pt.	22.8°C 22.2°C	22.3°C 21.7°C	-	-	-	22.0°C 21.4°C
Pressure	1012.4	1012.3	-	-	-	1011.9

3.8 Aids to Navigation

According to ICAO's "Regional Air Navigation Plan" the Zanderij Airport should be equipped with the following navigational aids:

a) one VOR
b) one NDB
c) one ILS Categor 1

There are three published instrument approach procedures for runway 10 at Zanderij. The limits for the ILS-DME procedure are: a minimum descent altitude (MDA) of 260 ft above sea level and a minimum visibility of 800 meters. The VOR/DME and the NDB have identical limits: an MDA of 560 ft and minimum visibility of 2300 m. A Notam published on 29 December 1988 announced that the ILS-DME was not available for operational use; the crew was aware of this. A test of the navigational aids by a specially equipped airplane on 13 June 1989 confirmed that the VOR, DME and NDB were functioning in accordance with the prescribed criteria. The middle marker was inoperative. The angle of the glidescope was within limits while the localizer alignment was unreliable. NDB "PZP" (336 KHz) was operational.

3.9 Communications

The traffic control communications equipment (123.9 MHz) and 118.1 MHz) was in good condition. However, the equipment that recorded the communications between traffic control and airplanes was not functioning.

3.10 Aerodrome Information

Zanderij International Airport (lat 05°27'21"N, long 55° 11' 11" W) is located about 45 km south of Paramaribo; its elevation is 54 ft. The runway is 3480 m long and 45 m wide. Runway 10 has high intensity runway and approach lights; runway 10 as well as runway 28 have a functioning Precision Approach Path Indicator (PAPI).

3.11 Flight Data-Recorder (FDR) and Cockpit Voice Recorder (CVR)

3.11.1 Flight Data Recorder

This model Lockheed 109C serial no. 1355 records the following parameters: altitude, airspeed, heading, acceleration and the keying of the transmitter microphone.

The last 10 minutes and 12 seconds of data have been transcribed. However, the altitude was not registered during this flight, due to the non-functioning of the related part of the recorder.

According to the FDR information, the runway heading was maintained during the final 5 1/2 minutes of the flight.

During the final 22 seconds of the flight the airspeed decreased gradually from 139 to 132 knots.

3.11.2 Cockpit Voice Recorder

The Cockpit Voice Recorder was a Fairchild A-100 model, serial no. 2388. The last 24 minutes of the flight as recorded by the CVR were transcribed verbatim by the NTSB Laboratory and verified by the Commission of Inquiry.

The CVR tape was not damaged. This tape continuously records information during the last 30 minutes of flight; it has 4 separate audio channels. Three of these are connected to the audio selector panel of the captain, the first officer and the flight engineer. The recording of information on these three channels is controlled by the keying of the microphone of the respective crew members. The fourth channel is connected to the open cockpit area microphone, which records all conversation in the cockpit.

3.12 Wreckage and Impact Information

The wreckage trail was "V" shaped and had a length of about 335 m with a width varying between 10 and 50 m. Parts of the cockpit equipment were found halfway down the wreckage trail. The fuselage was broken into pieces the longest of which were the empennage with the horizontal and vertical tail surfaces, and the wing center section. The center section with the main landing gear in the down-and-locked position was intact and had come to rest inverted. The cabin portion was totally destroyed.

3.13 Search of Hotel Rooms in Paramaribo

The search of the hotel rooms (Torarica) of the captain, the first officer and the flight engineer yielded nothing remarkable.

3.14 Fire Fighting

There was a postcrash fire. During the fire fighting activities of the airport fire department it became apparent that there was a shortage of adequate fire fighting equipment and no effective fire fighting plan as part of an all-inclusive disaster plan.

3.15 Survival Aspects

The rescue activities began at about 0453 local time, in darkness, following the fire extinguishing activities.

Despite the fire and the total destruction of the passenger cabin, 15 survivors were pulled from the wreckage of whom 7 (seven) died later. One child was found outside the wreckage.

3.16 Tests and Research

A delegation from the Commission visited the NTSB and FAA in Washington, D.C., between 19 and 29 July 1989, in order to verify the CVR Transcript and the data obtained from the FDR. There was also a discussion of the further course of action and additional information was obtained, especially with regard to the cockpit crew's professional and medical records. Moreover, the NTSB was requested to do everything possible to get a statement under oath from the Director of Air Crew International, Inc.

The FAA legal section was approached for a more detailed explanation of the interpretation of Federal Air Regulations Part 121, Part 129 and the Age-60 Rule. The Director of Air Crew International made a statement on 1 November 1989, in Miami, Florida.

In March 1990, the Douglas Aircraft Company in Long Beach, California, performed a simulation of the flight based on CVR and FDR data.

4. ANALYSIS

4.1 Analysis of CVR Transcript

The times listed in this section correspond with the times listed in the CVR Transcript.

It appears that the 0700 UTC weather report caught the crew by surprise, as evidenced by the captain's repeated question at 08.59 and 09.06: "What happened with the 6 kilometers (visibility)?"

This was followed by an intracockpit discussion (from 10.17 till 10.42) of published visibility minima. The fuel situation was also discussed (at 11.26). At 10.57 and again at 10.59 the copilot said: "We don't legally have an ILS". At 11.05 he stated: "We have to use it", to which the captain responded affirmatively at 11.10. The copilot's remarks at 11.21 "You can see the town over there" and at 13.05 "It must be very localized", as well as the captain's reaction at 13.07 "We'll take a shot at it" are indications that the crew believed that the fog reported at 08.26 was a localized phenomenon with discontinuities and that they could try to land.

This assumption finds additional support in the copilot's remark at 13.11 "We'll get in okay", followed by the captain's "Yeah" and the copilot's observation at 17.38 "You can see the airport down there no problem".

At 17.57 the first officer says "that's right here visibility won't be any problem". The captain responds with "Make a pass and ah we'll land that's all".

Following the controller's transmission that they could expect a clearance for a VOR/DME approach, the captain gives the instruction (at 21.00) "Put the ILS on my side". At 21.48 the tower at Zanderij issued to PY764 a clearance to conduct a VOR/DME approach to runway 10 and reported that the airplane was in sight.

At 22.02 the captain asked the first officer "Got the VOR on your side?" and instructed him to set the final approach course for the published VOR/DME approach on his (the first officer's) side. This cockpit configuration indicates that the captain may have planned to use the VOR/DME approach as a back-up for the ILS/DME approach.

At 23.07 the first officer told the captain "We're at nine DME" and at 23.12 he says "Yeah ah suppose to turn at seven". This is an indication that the DME of the VOR/DME was received on the first officer's side. With regard to the handling of the airplane it appears that the captain reacted slowly since the first officer repeatedly gave advisories to the captain, for example at 25.29 "Just keep on comin around on the thirty degree bank there you'll be all right" and at 25.38 "Get it on up to thirty degrees". Furthermore, the flight engineer states at 25.50 "Two thousand feet". The captain's reaction at 25.51 was "Huh?" followed by the first officer's call-out "Two thousand two thousand" to which the captain responded "Okay" and then "you mean I went through it so we'll come back..."

At 26.00 the first officer gave the captain additional advisories: "It's a level out it's about ten degrees to the right level out now you'll be all right".

That the first officer repeatedly switched back and forth from VOR to ILS is indicated by the discussion between the first officer and the flight engineer (from 26.11 to 26.15) about the inbound course for the approach and by the conversation between captain and first officer at 26.43 when the captain asked "How far out are we?" to which the first officer responded with "Let me get back on the DME".

At 27.41 the first officer reported that he could see the airport: "Runway's at twelve o'clock". At 28.32 he comments "A little bit of low fog comin' up I reckon just a little bit", and next he says "OKay it's down right right there ah close to the runway " apparently referring to a fog bank in the vicinity of the runway. At 28.28 he gave an affirmative answer to the tower's question whether he had the runway lights in sight. Apparently the airplane was in stratus clouds since the captain told the first officer at 30.56 "Tell him to turn the runway lights up" and again at 31.05 "Tell him to put the runway lights bright".

At 28.51 the first officer states "Glide slope alive"; at 30.09 the captain says "If I get a capture here I'll be happy"; and again at 30.24 "I didn't get no capture yet", which indicates that the glideslope for the ILS/DME approach had not been intercepted.

The captain's comment at 27.26 "I'm right on the localizer now" indicates that the localizer signals, which identify the extended center line of the runway, were received.

The conversation in the cockpit and the advisories given by the first officer lead to the conclusion that the captain was flying.

During the approach (between 30.48 and 31.02) the warning of the Ground Proximity Warning System sounded several times.

The "glideslope" warnings are no longer heard after 31.02. This suggests that a crew member probably deactivated the warning system while the airplane was still within the zone where a warning should have been triggered. According to the first officer's call at 31.33 ("Two hundred feet") the captain was flying the aircraft below the minimum altitude for the ILS/DME approach procedure (260 ft above sea level as well as below the minimum descent altitude for the VOR/DME approach procedure (560 ft). The first collision with the tree occured at 31.46.

It should also be noted that the warning signals of "glide slope" indicated that the airplane was flying under (below) the glidepath transmitted by the ILS and that the deviation kept increasing.

It is noteworthy that the airplane would have been at an altitude of at least 600 ft at the accident site if the pilot had flown the VOR/DME approach procedure for which he had been cleared, or if he had properly executed the ILS/DME approach procedure - although it was not operational.

4.2 Flight Path Reconstruction

With cooperation from McDonnell Douglas an attempt was made to reconstruct the final 10 minutes of flight PY764. CVR and FDR data were used for that purpose. However, the reconstruction was hampered by the fact that the FDR did not record altitude. That portion of the FDR was inoperative.

The following data points were used to reconstruct an approximation of the flight path:

- level terrain around the airport; elevation 54 ft
- altitude alert at 2000 ft (time index 21.14)
- altitude calls referred to height above sea level)
- distance calls were based on the VOR/DME
- standard pressure gradient
- wind from the surface till 8000 ft - calm
- the FDR ceased recording at time index 31.46

The airplane made its landing approach after completing a procedure turn.

The landing limits for this approach are an altitude of 560 ft and 2300 m visibility. It has already been mentioned that the reported visibility was 900 m. Examination of the radios showed that the crew had initiated an ILS/DME approach. The CVR confirms that this was indeed the case. The limits for an ILS/DME approach are an altitude of 260 ft above sea level ana 800 m visibility.

However, a Notam had been issued for the ILS, giving notice of its unreliability; the CVR indicates that the pilot was aware of this.

It is also apparent from the cockpit conversation that the flight progressed for a considerable time below the indicated glideslope of the ILS and that the crew was aware of this. No corrective action was taken.

The pilot had decided to descent to 200 ft. The CVR indicates that, at 200 ft, the pilot started to arrest the descent of the airplane. The airplane kept descending for a few more seconds, during which time a tree was struck.

The altimeter settings corresponded with the barometric pressure of 1012mb reported to the flight. The radar altimeter indicated 180 ft.

The reconstruction of the actual approach and landing procedure revealed that:

1. The cockpit crew knew that the use of the ILS was not authorized.
2. The crew received a clearance for the VOR/DME approach. Although they acknowledged this clearance, they proceeded to use the ILS.
3. During the approach procedure the crew descended deliberatedly below the minimum descent altitude of the VOR (560 ft) and that of the ILS (260 ft).
4. The first officer suggests that the airplane is too high despite the "glide slope" alarm, which warns that the airplane is below the glide slope.

4.3 Aircraft Performance

The Commission based its study of aircraft performance on data from the FDR, the CVR and the flight plan obtained from SLM operations. The weight and balance for this flight was calculated as follows:

Total Traffic Load	41.816	pounds
Dry Operating Weight	149.362	"
Zero Fuel Weight	191.177	"
Take-off fuel (actual)	139.311	"
Take-off gross weight	330.488	"
Estimated fuel burn	120.250	"
Estimated Landing Weight	210.237	"
Taxi fuel (not included above)	1.000	"

The take-off load limit was 26.0% MAC and for the landing with extended landing gear 18.2, while the aftmost limit at more than 195.000 lbs was 31.4.

The fuel requirements for the flight (actual take-off fuel) was calculated as follows:

Fuel for ETE plus 2% for high consumption	120.250	pounds
3% reserve for no alternate within 500 miles	3.610	"
10 minutes company imposed reserve	1.820	"
Alternate Cayenne plus 30 minutes	13.630	"
	139.310	pounds

The approach speeds (in knots) for an estimated landing weight of 210.237 lbs are as follows:

	Full Flap landing	35° Flap landing ("quiet approach")
Vref	127	132
FAS	132	137
12 bug	152	157
Obug	177	182

The crew probably used the quiet approach procedure with 35° flaps max.

The CVR and FDR do not give any indication that there were problems with the performance of the airplane or that one or more of the crew members were unable to discharge their duties.

4.4 The Role of Ground-based NavAids

Tests were made to determine to what extent the operation of the navigational and visual landing aids may have contributed to the accident . These aids were tested on 13 June 1989 by a specially equipped FAA airplane.

It was found that the NDB and VOR/DME functioned well while it was confirmed that some parameters of the ILS - as per previous notification - were unreliable. However, this FAA flight check team arrived at the conclusion that a safe landing could have been made if the pilot had adhered to the published ILS procedure.

4.5 Operational Control

The discovery during the investigation that the captain was not qualified to conduct this flight prompted the Commission to find an explanation for the presence of an unqualified pilot-in-command.

When the crew of this aircraft was recruited from ACI by SLM it was assumed that they were fully qualified and properly certificated to fly the DC8.

The investigation revealed that this background of the cockpit crew had not been examined, that no proficiency or route checks had been conducted and that the Aviation Department had not received information about the crew. ACI stated that the pilots themselves were responsible for arranging the required flight checks.

Documentation obtained from the FAA and NTSB shows that the captain and the flight engineer were licensed to fly DC8 - type airplanes. However, as the flight involved was a commercial, international flight, the captain was not authorized to act as pilot-in-command of this flight based on the current regulations of the USA and Surinameas well as the relevant international (ICAO) procedures which stem from the Chicago Convention.

According to Suriname Law — Art. 8 of the Decree of 27 November 1985 (S.B. 1985 no. 69) — the holder of a pilot certificate is not authorized to act as pilot during commercial flights when he/she has reached age 60.

Statements from SLM indicate that the company assumed that the Operating Permit issued by the FAA under FAR Part 129 included permission to conduct international flights without applying the age 60 limit to the pilots. However, said Part 129 is applicable only in the USA and, furthermore, this does not affect the applicability of Suriname aviation regulations in the operation of Suriname airlines, even if it involves flights to the USA or flights in aircraft registered in the USA.

Since the aircraft had American registration, the certification and qualification of the pilots were also governed by American regulations. In that regard American regulations stipulate that pilots-in-command of commercial flights conducted under FAR Part 129 may not be older than 60, in accordance with international regulations stemming from the Chicago Convention.

The information obtained also showed that the pilots had not completed the required periodic proficiency check on the type airplane (DC-8) within the prescribed period; as a result, they were not qualified to act as flight crew members.

According to statements from SLM personnel some incidents had occurred during SLM flights under the command of

- At Miami Airport he allowed the aircraft engines to develop full RPM in the vicinity of the terminal, contrary to existing directives; he ignored the admonition of airport officials.

- At Belem Airport the airplane left the runway and became stuck in the soil when too sharp a turn was made.
- At Lisbon Airport he made a hard landing with N1809E during a thunderstorm resulting in deflated tires and runway damage. This happened about four months before the PY 764 accident.

Following SLM's investigation of those incidents, ACI executives were forbidden to use the Captain in future SLM assignments; this directive took effect. Nevertheless, flight logs indicated that, since 24 May 1989, said captain again acted as a crew member (co-pilot) and on 4 June 1989 as pilot-in-command of a flight to Amsterdam. An employer of SLM's Logistics Department noted this and reported it to the directors of the Departments of Operations and Logistics; no action was taken.

The manager of Flight Operations was also aware that the Captain was again flying for SLM. HOwever, there is no evidence that further action was taken against him.

The investigation also indicated that the appropriate and responsible SLM officials (Manager Flight Operations, Director of Operations) often had no direct or indirect knowledge of the identity of the American flight crews who conducted the SLM DC-8 flights and of their qualifications and certification. The following procedure was used to muster flight crews:

The Manager of Flight Operations notified the Logistics Department of the requirement; this Department, in turn, would send a telex message to SLM-Miami and the latter would relay the requirements to ACI. ACI would then assign 3 persons (a pilot-in-command, a first officer and a flight engineer) to conduct SLM flights.

According to statements from ACI, , the competency and certification of those involved were generally not checked. This practice is contrary to the aviation regulations and the Operations Manual approved by the Aviation Department.

It is noted that within SLM there was no agreement about the scheduling of the captain. The company had insufficient insight in the qualifications of the flight crew while their operation of the flight was considered an "American operation". This could lead to the erroneous belief within SLM that the hired crew did not fall within the jurisdiction of SLM's Operations Department.

5. FINDINGS

5.1 Summary

a. The analysis of the CVR transcript, the FDR data and all other available information indicates that the aircraft was in a normally functioning, airworthy condition during the flight until the moment it struck the tree.

b. Investigation of the wreckage did not produce any evidence of a terrorist act or sabotage.

c. The flight crew was aware that:

   1. Air traffic control had cleared them for a VOR-DME approach.
   2. The reported weather was below the prescribed minima for a VOR-DME approach.
   3. The ILS was not to be used for operational purposes, which meant that the weather minima associated with the ILS were not applicable.

d. The captain decided to execute an approach procedure. However, that procedure did not follow the prescribed approach procedure for runway 10; one of the deviations involved not starting the procedure turn at the designated point. In addition, there was no adherence to the prescribed minimum altitudes, including the "Minimum Descend Altitude" as evidenced by the crash location. The CVR analysis indicates that the pilot used information from the ILS in that process, although he knew that the ILS was not available for operational use. Especially noteworthy in that regard is the observation that various warning signals in the cockpit were either ignored or turned off.

e. The CVR information also indicates that the pilot was actually in the process of making a visual landing as shown by his confirmation that he had the field in sight and also his repeated request to increase the intensity of the runway lights.

The refraction of light through the fog could have created a false impression of the real distance to the runway. As a result of the concentration on a visual landing during the final phases of the approach, little or no use was made of the information available in the cockpit which depicted the true position of the aircraft with regard to the runway.

f. The captain was aware of the fact that he was proceeding below the "normal" glide slope angle since the appropriate warning signals were audible in the cockpit.

g. It is noted that during the descent and approach, coordination in the cockpit was very poor; at the same time, the captain was slow in the performance of certain tasks or failed to make proper use of the information displayed on the instruments.

h. According to binding regulations the captain was not qualified to act as pilot-in-command of flight PY764 due to his age (beyond 60) and his most recent proficiency check flight on an aircraft other than a DC8.

i. ACI failed to furnish SLM with a qualified and properly licensed pilot-in-command in accordance with the contract.

j. The company failed to verify that ACI assigned qualified and properly licensed flight crew members to conduct the company's flights.

k. It was not clear who was directly responsible for the American crew and the exercise of control over training, competency, route checks, etc.

l. SLM did not inform the SurinameAviation Department about its contract with ACI. Furthermore, no information about the qualifications and licensing of the American pilots was ever forwarded to the Aviation Department.

5.2 CAUSE

The Commission determines:

a. That as a result of the captain's glaring carelessness and recklessness the aircraft was flown below the published minimum altitudes during the approach and consequently collided with a tree.

b. An underlying factor in the accident was the failure of SLM's operational management to observe the pertinent regulations as well as the procedures prescribed in the SLM Operational Manual concerning qualification and certification during the recruitment and employment of the crew members furnished by ACI.

RECOMMENDATIONS

The Commission of Inquiry wishes to make the following air safety recommendations:

1. The Commission's finding with regard to the lack of standardization in flight operations calls for improvements in the functioning of the company's organizational elements. Government surveillance of SLM must be strengthened.

2. All airline companies operating in Suriname should have a properly staffed and functioning Flight Operations Department that is familiar with the relevant regulations.

3. The Aviation Department has to strengthen its surveillance, especially with regard to the operational performance of air carriers.

4. It is recommended that more meteorological information be made available to airspace users by augmenting the existing ground equipment.

5. A comprehensive disaster plan, including adequate equipment for the agencies involved and an appropriate legal framework, are essential for efficient and vigorous search, rescue and investigation activities in connection with various types of disasters.

ICAO Note.— Names of personnel were deleted. Minor editorial changes were made.

ICAO Ref.: 145/89

No. 5

McDonnell-Douglas DC-10-10, N1819U, accident at Sioux City, Iowa, United States on 19 July 1989. Report No. NTSB/AAR-90/06 released by the National Transportation Safety Board, United States

EXECUTIVE SUMMARY

On July 19, 1989, at 1516, a DC-10-10, N1819U, operated by United Airlines as flight 232, experienced a catastrophic failure of the No. 2 tail-mounted engine during cruise flight. The separation, fragmentation and forceful discharge of stage 1 fan rotor assembly parts from the No. 2 engine led to the loss of the three hydraulic systems that powered the airplane's flight controls. The flightcrew experienced severe difficulties controlling the airplane, which subsequently crashed during an attempted landing at Sioux Gateway Airport, Iowa. There were 285 passengers and 11 crewmembers onboard. One flight attendant and 110 passengers were fatally injured.

The National Transportation Safety Board determines that the probable cause of this accident was the inadequate consideration given to human factors limitations in the inspection and quality control procedures used by United Airlines' engine overhaul facility which resulted in the failure to detect a fatigue crack originating from a previously undetected metallurgical defect located in a critical area of the stage 1 fan disk that was manufactured by General Electric Aircraft Engines. The subsequent catastrophic disintegration of the disk resulted in the liberation of debris in a pattern of distribution and with energy levels that exceeded the level of protection provided by design features of the hydraulic systems that operate the DC-10's flight controls.

The safety issues raised in this report include:

1. General Electric Aircraft Engines' (GEAE) CF6-6 fan rotor assembly design, certification, manufacturing, and inspection.
2. United Airlines' maintenance and inspection of CF6-6 engine fan rotor assemblies.
3. DC-10 hydraulic flight control system design, certification and protection from uncontained engine debris.
4. Cabin safety, including infant restraint systems, and airport rescue and firefighting facilities.

Recommendations concerning these issues were addressed to the Federal Aviation Administration, the Secretary of the Air Force, the Air Transport Association and the Aerospace Industries Association.

1. FACTUAL INFORMATION

1.1 History of Flight

United Airlines (UAL) flight 232 (UA 232), a McDonnell Douglas DC-10-10, registration No. N1819U, was a scheduled passenger flight from Stapleton International Airport, Denver, Colorado, to Philadelphia, Pennsylvania, with an en route stop at Chicago, Illinois. The flight was conducted under Title 14 Code of Federal Regulations (CFR) Part 121. Flight 232 departed Denver at 1409 central daylight time. There were 285 passengers and 11 crewmembers on board.

The takeoff and the en route climb to the planned cruising altitude of 37,000 feet were uneventful. The first officer (copilot) was the flying pilot. The autopilot was engaged, and the autothrottles were selected in the speed mode for 270 KIAS. The flight plan called for a cruise speed of Mach 0.83.

About 1 hour and 7 minutes after takeoff, at 1516:10, the flightcrew heard a loud bang or an explosion, followed by vibration and a shuddering of the airframe. After checking the engine instruments, the flightcrew determined that the No. 2 aft (tail-mounted) engine had failed. (See figure 1). The captain called for the engine shutdown checklist. While performing the engine shutdown checklist, the second officer (flight engineer) observed that the airplane's normal systems hydraulic pressure and quantity gauges indicated zero.

The first officer advised that he could not control the airplane as it entered a right descending turn. The captain took control of the airplane and confirmed that it did not respond to flight control inputs. The captain reduced thrust on the No. 1 engine, and the airplane began to roll to a wings-level attitude.

The flightcrew deployed the air driven generator (ADG), which powers the No. 1 auxiliary hydraulic pump, and the hydraulic pump was selected "on." This action did not restore hydraulic power.

At 1520, the flightcrew radioed the Minneapolis Air Route Traffic Control Center (ARTCC) and requested emergency assistance and vectors to the nearest airport. Initially, Des Moines International Airport was suggested by ARTCC. At 1522, the air traffic controller informed the flightcrew that they were proceeding in the direction of Sioux City; the controller asked the flightcrew if they would prefer to go to Sioux City. The flightcrew responded, "affirmative." They were then given vectors to the Sioux Gateway Airport (SUX) at Sioux City, Iowa. (See figure 2). Details of relevant air traffic control (ATC) communications, cockpit conversations, airplane maneuvers, and airplane and engine system parameters are contained in Sections 1.9 and 1.11 of this report.

Crew interviews indicate that shortly after the engine failure, the passengers were informed of the failure of the No. 2 engine, and the senior flight attendant was called to the cockpit. She was told to prepare the cabin for an emergency landing. She returned to the cabin and separately informed the other flight attendants to prepare for an emergency landing. A flight attendant advised the captain that a UAL DC-10 training check airman, who was off duty and seated in a first class passenger seat, had volunteered his assistance. The captain immediately invited the airman to the cockpit, and he arrived about 1529.

At the request of the captain, the check airman entered the passenger cabin and performed a visual inspection of the airplane's wings. Upon his return, he reported that the inboard ailerons were slightly up, not damaged, and that the spoilers were locked down. There was no movement of the primary flight control surfaces. The captain then directed the check airman to take control of the throttles to free the captain and first officer to manipulate the flight controls.

The check airman attempted to use engine power to control pitch and roll. He said that the airplane had a continuous tendency to turn right, making it difficult to maintain a stable pitch attitude. He also advised that the No. 1 and No. 3 engine thrust levers could not be used symmetrically, so he used two hands to manipulate the two throttles.

About 1542, the second officer was sent to the passenger cabin to inspect the empennage visually. Upon his return, he reported that he observed damage to the right and left horizontal stabilizers.

Fuel was jettisoned to the level of the automatic system cutoff, leaving 33,500 pounds. About 11 minutes before landing, the landing gear was extended by means of the alternate gear extension procedure.

The flightcrew said that they made visual contact with the airport about 9 miles out. ATC had intended for flight 232 to attempt to land on runway 31, which was 8,999 feet long. However, ATC advised that the airplane was on approach to runway 22, which was closed, and that the length of this runway was 6,600 feet. Given the airplane's position and the difficulty in making left turns, the captain elected to continue the approach to runway 22 rather than to attempt maneuvering to runway 31. The check airman said that he believed the airplane was lined up and on a normal glidepath to the field. The flaps and slats remained retracted.

During the final approach, the captain recalled getting a high sink rate alarm from the ground proximity warning system (GPWS). In the last 20 seconds before touchdown, the airspeed averaged 215 KIAS, and the sink rate was 1,620 feet per minute. Smooth oscillations in pitch and roll continued until just before touchdown when the right wing dropped rapidly. The captain stated that about 100 feet above the ground the nose of the airplane began to pitch downward. He also felt the right wing drop down about the same time. Both the captain and the first officer called for reduced power on short final approach.

The check airman said that based on experience with no flap/no slat approaches he knew that power would have to be used to control the airplane's descent. He used the first officer's airspeed indicator and visual cues to determine the flightpath and the need for power changes. He thought that the airplane was fairly well aligned with the runway during the latter stages of the approach and that they would reach the runway. Soon thereafter, he observed that the airplane was positioned to the left of the desired landing area and descending at a high rate. He also observed that the right wing began to drop. He continued to manipulate the No. 1 and No. 3 engine

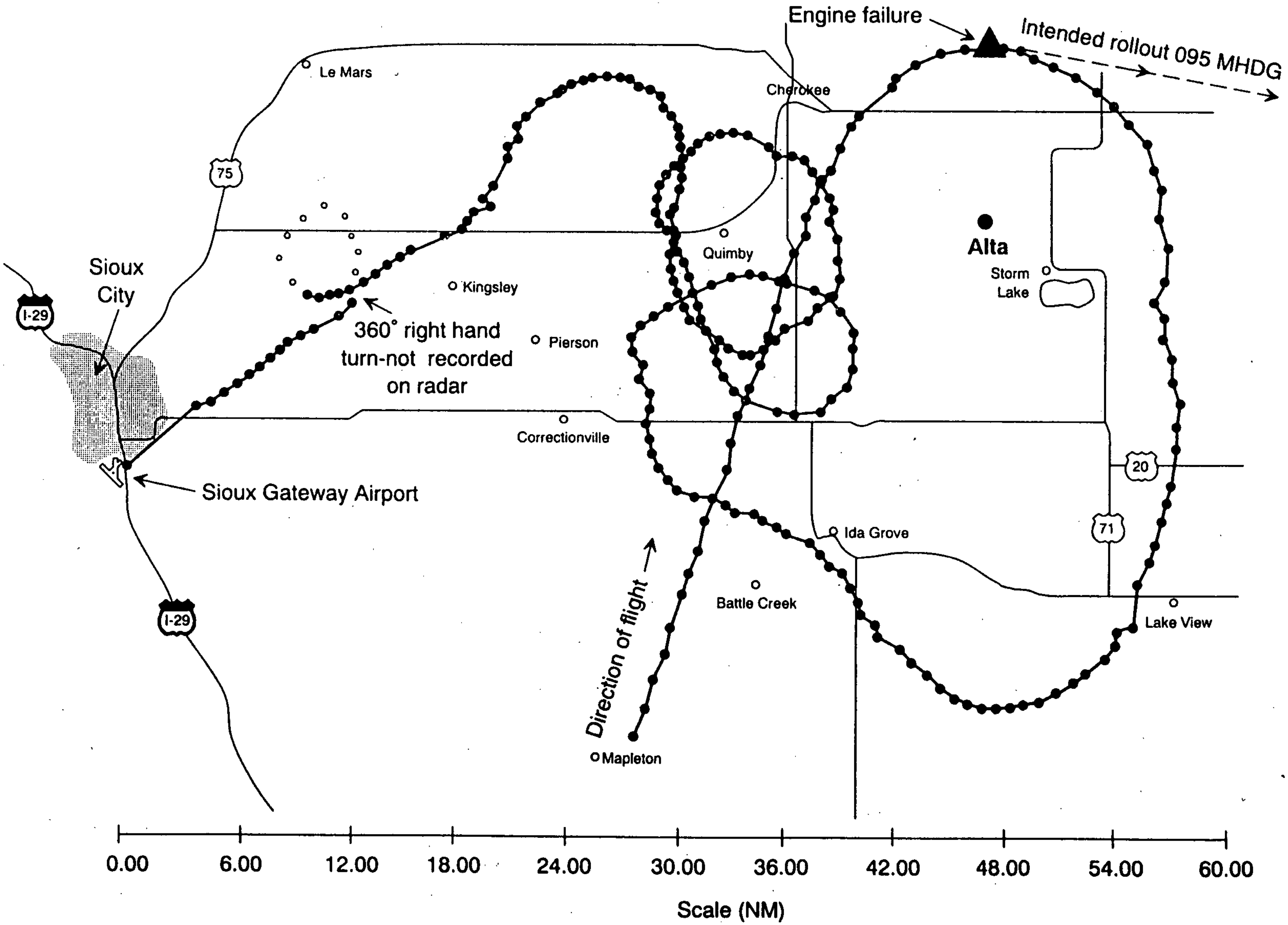

Figure 2.--Ground track from radar plot.

throttles until the airplane contacted the ground. He said that no steady application of power was used on the approach and that the power was constantly changing. He believed that he added power just before contacting the ground.

The airplane touched down on the threshold slightly to the left of the centerline on runway 22 at 1600. First ground contact was made by the right wing tip followed by the right main landing gear. The airplane skidded to the right of the runway and rolled to an inverted position. Witnesses observed the airplane ignite and cartwheel, coming to rest after crossing runway 17/35. Firefighting and rescue operations began immediately, but the airplane was destroyed by impact and fire.

The accident occurred during daylight conditions at 42° 25′ north latitude and 96° 23′ west longitude.

1.2 Injuries to Persons

Injuries	Crew	Passengers	Others	Total
Fatal	1	110	0	111
Serious	6	41*	0	47
Minor	4	121	0	125
None	0	13	0	13
Total	11	285	0	296

1.3 Damage to Airplane

The airplane was destroyed by impact and postcrash fire.

Photographs of the airplane were taken by observers on the ground during its final approach to Sioux Gateway Airport. They showed that the No. 2 engine fan cowling and the fuselage tail cone were missing. The remainder of the No. 2 engine appeared intact. Postcrash examination of the wreckage revealed that the No. 2 engine fan rotor components forward of the fan forward shaft, as well as part of the shaft, had separated from the engine in flight. (See figures 3 through 5).

The airplane's right wing began to break up immediately following touchdown. The remainder of the airplane broke up as it tumbled down the runway. The fuselage center section, with most of the left wing still attached, came to rest in a corn field after crossing runway 17/35.

The cockpit separated early in the sequence and came to rest at the edge of runway 17/35. The largely intact tail section continued down runway 22 and came to rest on taxiway "L." The engines separated during the breakup. The No. 1 and No. 3 engines came to rest near taxiway "L" and the intersection of runway 17/35, between 3,000 and 3,500 feet from the point of first impact. (See figure 6).

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*One passenger died 31 days after the accident as a result of injuries he had received in the accident. In accordance with 49 CFR 830.2, his injuries were classified "serious."

The No. 2 engine came to rest on taxiway "J" to the left of runway 22, about 1,850 feet from the point of first impact. The majority of the No. 2 engine fan module was not found at the airport.

The value of the airplane was estimated at $21,000,000.

1.4 Other Damage

Airplane parts, which separated and fell to the ground on cultivated land, caused no significant damage. There was some minor damage to airport facilities and adjacent crops as a result of the crash landing.

1.5 Personnel Information

The flightcrew consisted of a captain, first officer, second officer and eight flight attendants. (See appendix B).

The captain was employed by UAL on February 23, 1956. He had 29,967 hours of flight time logged with UAL, 7,190 hours of which was in the DC-10. He held an airline transport pilot certificate with type ratings in the DC-10 and B-727. He possessed a current first class airman medical certificate. His most recent proficiency check in the DC-10 was completed on April 26, 1989.

The first officer began airline employment on August 25, 1969. He estimated that he had logged 20,000 hours of flight time. He had accrued 665 hours as a first officer in the DC-10. He held an airline transport pilot certificate with type ratings in the DC-10 and L-1011. He possessed a current first class airman medical certificate. His most recent proficiency check in the DC-10 was completed on August 8, 1988.

The second officer was employed by UAL on May 19, 1986. He estimated that he had 15,000 hours of flight time. UAL records indicated that he had accumulated 1,903 hours as a second officer in the B-727 and 33 hours in the DC-10. He held a flight engineer certificate for turbojet airplanes. He possessed a current second class airman medical certificate. His most recent proficiency check in the DC-10 was completed on June 8, 1989.

A review of flightcrew duty time indicated that the crew had complied with all relevant duty time limitations. The accident occurred on the third day of a 4-day scheduled trip sequence. The crew had a 22-hour layover in Denver prior to the departure of flight 232. The cockpit crew had flown together six times in the previous 90 days.

The off-duty check airman was employed by UAL on January 2, 1968. He held an airline transport pilot certificate with type rating in the DC-10 and a first class medical certificate. He had completed captain-transition training in the DC-10 on April 25, 1989, and was assigned as a DC-10 training check airman at UAL's Flight Training Center in Denver, Colorado. He had about 23,000 hours total flight time with 2,987 hours logged in the DC-10. He had 79 hours as captain in the DC-10.

1.6 Airplane Information

UAL operated a total of 55 DC-10 airplanes; 47 airplanes were model DC-10-10, and 8 airplanes were model DC-10-30. The accident airplane, N1819U, fuselage No. 118, factory S/N 44618, was delivered in 1971 and was owned by UAL since that time. Prior to departure on the accident flight from Denver on July 19, 1989, the airplane had been operated a total of 43,401 hours and 16,997 cycles.

The maximum certificated takeoff weight for N1819U was 430,000 pounds. The center of gravity (CG) computed for departure was 21.9 percent mean aerodynamic chord (MAC). The calculated CG limits for this gross weight were 13.4 percent and 30.8 percent MAC, respectively. The takeoff gross weight was 369,268 pounds.

The accident airplane was powered by General Electric Aircraft Engines (GEAE) CF6-6D high bypass ratio turbofan engines. The CF6-6 engine was certified by the FAA on September 16, 1970.

Table 1 provides identification and historical information for the engines in N1819U at the time of the accident.

Table 1

Engines Historical Data

Data	Number 1	Number 2	Number 3
Engine Serial Number (ESN)	451-170	451-243	451-393
Total Time	44,078	42,436	39,338
Total Cycles	16,523	16,899	11,757
Time Since Last Maintenance	1,047	2,170	338
Cycles Since Last Maintenance	358	760	116
Time Since Last Shop Visit	3,635	2,170	338
Cycles Since Last Shop Visit	1,318	760	116
Date of Installation	5-9-88	10-25-88	6-11-89

Figure 7 contains a cutaway sectional drawing of the flow path and construction of the CF6-6 engine. The figure also shows the fan and accessory drive sections. Figure 8 displays the CF6-6 rotating assemblies. The portion of the No. 2 engine that departed the airplane is outlined by the dashed lines.

1.6.1 No. 2 Engine Historical Data

Engine S/N 451-243 was first installed on June 23, 1972, in the No. 3 position of a UAL DC-10-10, registration airplane N1814U. Fan module S/N 51406, which contained stage 1 fan disk P/N 9137M52P36, S/N MPO 00385, was installed on engine S/N 451-243 during a shop visit in July 1988, at UAL. At that time, the engine had accumulated 40,266 hours and 16,139 cycles since new.

Engine S/N 451-243 was installed in the No. 1 position on UAL airplane registration N1807U on September 15, 1988. It was removed "for convenience" 8 days later after one flight and was installed in the No. 2 position on N1819U on October 25, 1988. The engine had accumulated 42,436 hours and 16,899 cycles at the time of the accident.

Examination of service records, crew writeups, action items, trend monitoring data, and flight recorder data indicated no abnormal engine operation prior to the in-flight incident, with the exception of certain autothrottle anomalies. The autothrottle system's inability to hold steady N_1 was noted in the reported difficulties, and corrective action entries in UAL's Aircraft Maintenance Information System (AMIS) were dated on July 14, 17, and 19, 1989. On July 19, corrective action for the discrepancy was indicated accomplished at Philadelphia with the replacement of the autothrottle speed control and was signed off as "system ops check normal."

1.6.2 Stage 1 Fan Disk Historical Data

The stage 1 fan disk, part number (P/N) 9137M52P36,[1] S/N MPO 00385, was processed in the manufacturing cycle at the GEAE-Evendale, Ohio, factory from September 3 to December 11, 1971. It was installed as a new part in engine S/N 451-251 in the GEAE production assembly facility in Evendale. The engine was shipped to Douglas Aircraft Company on January 22, 1972, where it was installed on a new DC-10-10.

During the next 17 years, the engines in which this stage 1 fan disk were installed were routinely overhauled and the fan module was disassembled. The disk was removed on the following dates for inspection: September 1972, November 1973, January 1976, June 1978, February 1982 and February 1988. This disk was accepted after each of six fluorescent penetrant inspections (FPI).[2] (See figure 9). Five of the six inspections were performed at the UAL CF6 Overhaul Shop in San Francisco, California. One of them was performed at the GEAE Airline Service Department in Ontario, California, in 1973. At the time of the accident, the stage 1 fan disk had accumulated 41,009 hours and 15,503 cycles since new. The last shop visit in February 1988, was 760 flight cycles before the accident, and FPI was performed at that time. The engine had been removed because of corrosion in the high pressure turbine (HPT) stage 1 nozzle guide vanes. At that time, the stage 1 fan disk had accumulated 38,839 hours and 14,743 cycles since new. Following this inspection, the disk was installed in engine S/N 451-243, the No. 2 engine on the accident airplane.

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[1] Original P/N 9010M27P10 was superseded when the disk was modified during a GEAE shop visit in 1973. The fan blade dovetail slots were rebroached at that time.

[2] Fluorescent penetrant inspection (FPI) is the accepted industry inspection technique for interrogating nonferrous (nonmagnetic) component surfaces for discontinuities or cracks. The technique relies on the ability of a penetrant (a low-viscosity penetrating oil containing fluorescent dyes) to penetrate by capillary action into surface discontinuities of the component being inspected. The penetrant fluid is applied to the surface and allowed to penetrate into any surface discontinuities. Excess penetrant is then removed from the component surface. A developer is then applied to the component surface to act as a blotter and draw the penetrant back out of the surface discontinuity, producing an indication which fluoresces under ultraviolet lighting.

1.6.3 Airplane Flight Controls and Hydraulics--Description

Primary flight controls on the DC-10-10 consist of inboard and outboard ailerons, two-section elevators, and a two-section rudder. Secondary flight controls consist of leading edge slats, spoilers, inboard and outboard flaps, and a dual-rate movable horizontal stabilizer. Flight control surfaces are segmented to achieve redundancy. Each primary and secondary control surface is powered by two of three independent hydraulic systems.

The No. 1 hydraulic system provides power to the right inboard aileron and the left outboard aileron, the right inboard and outboard elevators, the left outboard elevator, the upper rudder, the horizontal stabilizer trim, and the captain's brake system. The No. 2 hydraulic system provides power to the right outboard aileron and the left inboard aileron, the inboard and outboard elevators on the left side, the outboard elevator on the right side, and the lower rudder. It also provides power to the isolated closed-loop system that operates the upper rudder. The No. 3 hydraulic system provides power to the right inboard and outboard aileron and the left inboard aileron, the inboard elevators on the right and left side, horizontal stabilizer trim, and the first officer's brake system. It also drives an isolated closed-loop system that powers the lower rudder actuator. These closed-loop arrangements allow for operation of the remaining parts of hydraulic systems No. 2 and No. 3 in the event of damage to the rudder hydraulic system. (See figure 10).

The three independent, continuously operating hydraulic systems are intended to provide power for full operation and control of the airplane in the event that one or two of the hydraulic systems are rendered inoperative. System integrity of at least one hydraulic system is required--fluid present and the ability to hold pressure--for continued flight and landing; there are no provisions for reverting to manual flight control inputs.

Each hydraulic system derives its power from a separate engine, with a primary and a reserve engine-driven pump providing hydraulic pressure. Either of these pumps can supply full power to its system. Backup power is provided by two reversible motor pumps, which transmit power from one system to another without fluid interconnection. This backup power system activates automatically without requiring flightcrew control, if fluid is still available in the unpowered system.

Electrical power can be used to drive either of two auxiliary pumps provided for the No. 3 hydraulic system. In an emergency situation where the engine-driven pumps are inoperative, an air-driven generator can be deployed into the airstream to supply electrical power to one of these auxiliary pumps.

The hydraulic components and piping are physically separated to minimize the vulnerability of the airplane to multiple hydraulic system failures in the event of structural damage. The No. 1 hydraulic system lines run along the left side of the fuselage to the rear of the airplane and along the front spar of the horizontal stabilizer and the vertical stabilizer. The No. 2 hydraulic system lines are routed from the center engine along the rear spar of the horizontal and vertical stabilizers. The No. 3 hydraulic system lines run along the right side of the fuselage to the tail area and along the rear spar of the horizontal stabilizer. The No. 2 hydraulic system lines are not routed forward of the rear wing spar, in order to isolate them from wing engine fragmentation, and No. 3 hydraulic system lines in the tail section are not routed aft of the inboard elevator actuators in order to minimize exposure to possible engine fragmentation damage from the tail-mounted engine.

The DC-10-10 hydraulic system was designed by the manufacturer and demonstrated to the FAA to comply with 14 CFR 25.901, which in part specified that, "no single [powerplant] failure or malfunction or probable combination of failures will jeopardize the safe operation of the airplane...."

1.7 Meteorological Information

The surface weather observation taken at Sioux Gateway Airport at 1559 estimated a ceiling of 4,000 feet with broken clouds and 15 miles visibility. The temperature was 80° F, and winds were 360° at 14 knots. There were towering cumulus clouds in all quadrants. The last wind reported to the crew by the tower at 1558 was from 010° at 11 knots.

1.8 Aids to Navigation

Instrument Landing System (ILS) approaches for runways 31 and 13 were available. When runway 22/04 was closed in 1988, published instrument approaches to that runway were cancelled. Electronic aids to navigation were not used by the crew of UA 232.

1.9 Communications

1.9.1 United Airlines Company Flight Following

At 1521, UA 232 sent an Aircraft Communications and Reporting System (ACARS) message to UAL's central dispatch facility[3] in Chicago, Illinois, requesting a call on frequency 129.45. Dispatch was initially unsuccessful in establishing voice contact. At 1523, dispatch initiated an ACARS call to UA 232 that resulted in positive contact.

The communication between UA 232, UAL's dispatch facility and UAL's San Francisco maintenance facility (SAM) was recorded by Aeronautical Radio Incorporated (ARINC). The recording revealed that, at 1525, UA 232 requested that dispatch put the flight in contact with "SAM immediately, it's a MAYDAY." UA 232's initial conversation with SAM occurred at 1527. The crew advised SAM of the loss of all hydraulic systems and quantities and requested whatever assistance SAM could provide. SAM was unable to provide instructions to the flightcrew that they did not already have.

At 1533, SAM informed UA 232 that it was making contact with UAL Flight Operations. At 1540, SAM advised the flightcrew that representatives of UAL's "Operational Engineering" department had been contacted to lend assistance. At 1545, SAM informed the flightcrew that, "Engineering is

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[3] Dispatch facility - the air carrier section operating in accordance with Part 121, Subpart U - Dispatching and Flight Release Rules for flight planning, release, and monitoring of air carrier operations.

assembling right now and they're listening to us." UA 232 then advised SAM that the flight was at 9,000 feet and that they were planning to try to land at Sioux City. At 1549, the flightcrew informed SAM that they had just completed the alternate gear extension procedure. This communication was the last one ARINC recorded from UA 232.

The dispatcher working UA 232 stated that UAL Flight Operations asked her to inquire of the flightcrew about the possibility of landing in Lincoln, Nebraska, instead of Sioux City. Flight Operations was concerned about crosswinds and the need for a longer runway. The dispatcher forwarded this inquiry to the flightcrew at 1554 but did not receive a reply.

The dispatch office also received a call from UAL personnel in Sioux City stating that a DC-10 was east of the field experiencing difficulty. Dispatch contacted the Sioux Gateway Airport ATC tower directly and requested the dispatching of all emergency crash, fire, and rescue equipment.

1.10 Airport Information

Sioux Gateway Airport serves Sioux City, Iowa, and is 6 nmi south of the city on a flat plain adjacent to the east bank of the Missouri River. Its elevation is 1,098 feet. The airport is owned and operated by the city as a public-use airport.

The airport is currently served by two runways. Runway 17/35, of asphalt construction, is 150 feet wide by 6,599 feet long. Both ends have overruns; 850 feet on the north end and 794 feet on the south end. Runway 13/31 is 150 feet wide by 8,999 feet long with 1,000 feet of overrun on the southeast end.

Runway 4/22 has a concrete surface, 150 feet wide by 6,888 feet long. It has paved shoulders 75 feet wide on each side, from the threshold area of runway 22 to the intersection with runway 13/31. Runway 22 has a turf overrun 550 feet long on its approach end, with a short asphalt base section just in front of the threshold. The terrain past the rollout end is cropland. Elevation at the threshold of runway 22 is 1,095 feet. The runway is marked with a yellow "X" painted over the numbers at each end to indicate that the runway is closed.

Sioux Gateway Airport is an "Index B" airport under 14 CFR 139. The airport "Index" is based on the size of scheduled air carrier aircraft that normally use that facility and the average daily departures of airplanes--in this case--DC-9, B-737, and B-727-100 series airplanes. A full-scale emergency exercise is required under 14 CFR 139 every 3 years, and a "table-top" review of the Airport Emergency Plan is required annually. A mass casualty exercise was conducted at the airport on October 10, 1987, that included the evacuation of about 90 casualties. The most recent drill was conducted on June 16, 1989. During the postaccident discussions, emergency personnel indicated that their preparedness training was a tremendous asset in this response.

DC-10 airplanes are not normally scheduled to land at Sioux Gateway Airport and require the use of an "Index D" airport, which recommends more than twice the quantity of firefighting extinguishing agents required of an "Index B" airport.

Aircraft rescue and firefighting (ARFF) services at the Sioux Gateway Airport are provided by the Iowa Air National Guard (ANG) through a joint-use agreement with the National Guard Bureau, the State of Iowa, and the City of Sioux City. Additionally, the local community reaction plan is coordinated with airport emergency services by the FAA control tower during its hours of operation through the Woodbury County Disaster and Emergency Services Communications Center in Sioux City.

1.11 Flight Recorders

1.11.1 Cockpit Voice Recorder

The airplane was equipped with a Sundstrand Model AV557B, serial no. 7510, cockpit voice recorder (CVR) that provided a good record of air traffic control and intracockpit communications for the last 33 minutes and 34 seconds of the flight. The recording began at 1526:42, during a transmission made by the captain to Sioux City Approach Control about 10 minutes after the No. 2 engine had failed.

At 1529:15, the CVR revealed a flight attendant relaying a message to the captain. The captain responded, "okay let'em come up" to the flightdeck. At 1529:35, the check airman arrived on the flightdeck. At 1529:41, the captain explained, "we don't have any controls." Fourteen seconds later, the captain directed the check airman to return to the cabin to determine if he could see any external damage to the airplane through the windows.

At 1530:32, the first officer asked, "What's the hydraulic quantity." The second officer reported that it was zero, followed by the first officer asking, "on all of them," and the second officer confirming the status. The captain followed by saying, "quantity is gone?" Three seconds later, he asked the second officer, "you got a hold of SAM?" The second officer reported, "he's not telling me anything." The captain responded, "we're not gonna make the runway fellas." At this point, it is believed that the check airman returned to the flightdeck, and the captain reported, "we have no hydraulic fluid, that's part of our main problem." The check airmman stated, "okay both your inboard ailerons are sticking up that's as far as I can tell. I don't know." He then asked the captain for instructions, and the captain told him which throttle to manipulate. At 1532:02, the check airman reported that the flight attendants were slowly securing the cabin and the captain reported that "they better hurry we're gonna have to ditch I think."

At 1532:16, the captain reported to the approach controller that the flight had no hydraulic fluid and therefore no elevator control and that the flight might have to make a forced landing. Two seconds after the captain began his transmission, the check airman stated, "get this thing down we're in trouble." At 1534:27, the captain decided to attempt a landing at Sioux City and asked the second officer for information to make a no-flap, no-slat landing. He also asked the controller for the ILS frequency heading to the runway and the length of the runway. The controller provided the frequency and reported runway 31 to be 9,000 feet long. At this point, the airplane was about 35 miles northeast of the airport.

At 1535:36, the captain instructed the second officer to start dumping fuel by using the quick dump. At 1537:55, the captain asked the check airman if he could manipulate the throttles to maintain a 10° to 15° turn, and the check airman replied that he "would try." At 1538:55, one of the pilots said that 200 knots would be the "clean maneuvering airspeed," and the first officer responded with, "two hundred and one eighty five on your bugs Al."

At 1540:39, the captain asked the senior flight attendant if everyone in the cabin was ready. The captain explained to the flight attendant that they had very little control of the airplane because of the loss of hydraulic flight controls and that they were going to attempt to land at Sioux City, Iowa. He stated that it would be a difficult landing and that he had doubts about the outcome and the crew's ability to carry out a successful evacuation. He said that there would be the signal "brace, brace, brace" made over the public address system to alert the cabin occupants to prepare for the landing. At 1541:09, the approach controller again informed the flight that emergency equipment would be standing by.

At 1541:52, the second officer reported that a flight attendant said she observed damage on one wing. He asked if he should go aft and look. The captain authorized his absence from the flightdeck to investigate. The second officer returned about 2-1/2 minutes later to report that there was damage to the tail of the airplane, and the captain stated, "...that's what I thought." At 1548:43, the landing gear was extended. At 1549:11, the captain directed the flightcrew to lock their shoulder harnesses and to put everything away.

At 1551:04, ATC reported that the airplane was 21 miles north of the airport. The controller requested the flight to widen its turn slightly to the left in order to make a turn onto its final approach and to keep the airplane away from the city. The captain responded, "whatever you do, keep us away from the city." Several seconds later, the controller gave the flight a heading of 180°. At 1552:19, the controller alerted the crewmembers to a 3,400-foot tower obstruction located 5 miles to their right. The first officer acknowledged. At 1552:34, the controller asked how steep a right turn the flight could make. The captain responded that they were trying to make a 30° bank. A cockpit crewmember commented, "I can't handle that steep of bank...can't handle that steep of bank."

At 1553:35, the first officer stated, "...we're gonna have to try it straight ahead Al..." followed 2 seconds later by the controller advising the crew that if they could hold altitude, their right turn to 180° would put the flight about 10 miles east of the airport. The captain stated, "that's what we're tryin' to do." The first officer then recommended that they try to establish a shallow descent. Twenty seconds later, the captain stated that he wanted to get as close to the airport as possible. Seconds later, he stated, "get on the air and tell them we got about 4 minutes to go." The first officer so advised the controller, but the captain corrected him, saying, "tell the passengers," at which time a crewmember made a PA announcement. At 1555:44, the captain reported a heading of 180°. The controller reported that if the altitude could be maintained, the heading, "will work fine for about oh 7 miles."

At 1557:07, the controller reported to the flight that the airport was "...twelve o'clock and one three miles." At 1558:11, the captain reported the runway in sight and thanked the controller for his help. The captain instructed the second officer to make a PA announcement, which was believed to be a 2-minute warning. The controller reported the winds as 360° at 11 knots and cleared the flight to land on any runway. At this point, the flightcrew attempted to turn the airplane to the left slightly. At 1558:59, the captain reported, "we're pretty well lined up on this one here...think we will be..." The controller stated that the runway the flight had lined up on was runway 22, which was closed, but he added "that'll work sir, we're gettin' the equipment off the runway, they'll line up for that one." The captain asked its length, and the controller reported it as 6,600 feet long. Twelve seconds later, the controller stated that there was an open field at the end of the runway and that the winds would not be a problem. During the interim seconds, the crew's attention was directed to manipulating the throttles. At 1559:29, one of the crewmembers made the PA announcement to brace for the landing.

At 1559:44, the first of several ground proximity warning system alerts (GPWS) began and ended 8 seconds later. At 1559:58 the captain stated "close the throttles." At 1600:01, the check airman stated "nah I can't pull'em off or we'll lose it that's what's turnin' ya." Four seconds later, the first officer stated, "left Al" followed by "left throttle" left [repeated several times]. A second series of GPWS alerts begin at 1600:09, followed by the first officer stating several times, "we're turning" or "we're tryin." The sound of the impact occurred at 1600:16.

1.11.2 Flight Data Recorder

The flight data recorder (FDR) was a Sundstrand Model 573 (S/N 2159). It was found undamaged, and there was no evidence of excessive wear. The quality of the data recording was generally good, although some anomalies in the data did occur. The recorded data included altitude, indicated airspeed, heading, pitch attitude, roll attitude, stabilizer position, fan rotor speed (N1) for each engine, vertical acceleration, position of control surfaces, longitudinal acceleration, and lateral acceleration.

The FDR contained a full 25 hours of recorded data. The data for the July 19 Denver-Chicago flight and the previous flights on the tape were transcribed and examined for anything unusual in the N_1 record for the No. 2 engine. All prior recorded engine parameters were normal.

The data revealed no evidence of RPM that exceeded the maximum allowable limit of 111 percent N_1 for flights prior to the accident flight. However, the data did reveal cyclic excursions in N_1 within allowable values on all three engines.

The FDR operated normally until ground impact, except for three periods in which the data stream was interrupted and data were lost. The first loss occurred shortly after takeoff during a track switch within the recorder. The second loss of 44 seconds of data occurred approximately 9 minutes before the No. 2 engine failed. The third loss occurred at the time of the No. 2 engine failure, resulting in the loss of approximately 0.7 seconds of data. The FDR data showed that the No. 2 engine failed at 1516:10.

The FDR data for the conditions that existed just prior to the No. 2 engine failure--the last data point before the failure--were:

Pressure Altitude	36,991 feet
Indicated Airspeed	271.25 knots
Total Air Temperature	-17 degrees C.
Magnetic Heading	82.27 degrees
Pitch Angle	2.812 degrees
Bank Angle	20.04 degrees
Fan Speed, No. 1 engine	102.86 percent[4]
Fan Speed, No. 2 engine	102.69 percent
Fan Speed, No. 3 engine	103.59 percent
Vertical Load Factor	1.0556 g's
Longitudinal Load Factor	(+).0708 g's
Lateral Load Factor	(-).0030 g's

1.12 Wreckage and Impact Information *

1.13 Medical and Pathological Information

Of the 296 persons aboard the airplane, 110 passengers and 1 flight attendant were fatally injured. Autopsies revealed that 35 passengers died of asphyxia due to smoke inhalation, including 24 without traumatic blunt force injuries. The other fatally injured occupants died of multiple injuries from blunt force impact. Of the remaining 185 persons onboard, 47 sustained serious injuries, 125 sustained minor injuries, and 13 were not injured. (See figure 15).

1.14 Fire

There was no evidence of in-flight fire. A postcrash fire erupted during the crash breakup of the airplane. A deep-seated fuel-fed fire took place in the cabin wreckage.

1.14.1 Airport Response

The FAA control tower advised the airport fire department of a DC-10 in-flight emergency about 1525. A total of five ARFF vehicles were dispatched. These units were assisted by four Sioux City Fire Department vehicles, which were dispatched to the airport before the crash as part of the community emergency response plan.

During the response, information relayed from the control tower to these units indicated that the airplane might not reach the airport and that it could crash approximately 5 miles south of the airport.

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[4] Speed is indicated as a percent of a rotor design reference speed. It does not indicate a percent of a rated speed or rated thrust.

**ICAO Note.*— Section 1.12 was not reproduced.

At 1547, the fire chief was advised by the control tower that the airplane was going to reach the airport and that it would land on Runway 31. Firefighting units immediately took positions along runway 31 and awaited the arrival of the airplane.

At 1559, the control tower advised ARFF personnel that the DC-10 would land on runway 22 instead of runway 31. Further, the tower informed the fire chief that some of his vehicles were aligned with the approach path of the DC-10 and that they should be moved immediately.

Before all units were repositioned, the airplane touched down, began to break up, and a fire ignited. The center section, which contained the majority of passengers, was inverted and came to rest in a corn field about 3,700 feet from the initial impact area.

After the crash, all ARFF vehicles proceeded to the intersection of runways 22 and 17, and the fire chief radioed the 185th Tactical Fighter Group Command Post directing all available personnel and equipment to respond to the accident scene.

About 1601, after briefly inspecting the tail section of the airplane, the fire chief directed all units to proceed to the center section of the airplane. While responding to this location, some passengers were found in their seats and others were walking along runway 17.

A significant fire was burning, mostly on the exterior of the wreckage. The fire chief learned from exiting passengers that other passengers could be located among the cornstalks, which were approximately 7 feet high. The emerging passengers later stated that they were disoriented by these tall cornstalks.

The first ARFF vehicle to arrive at the scene sprayed a massive application of foam to blanket the surface of the inverted center section. The fire chief reported that the foam application could easily reach the right wing. Some passengers reported that they were sprayed with foam while exiting the airplane.

The fire chief reported that the fire was located primarily underneath the right wing box area and along the front portion of the fuselage. He said that the 10- to 12-knot wind from the north helped to keep the fire away from the fuselage.

About 1604, the first vehicle to arrive on the scene had exhausted its onboard water supply. By this time, a second vehicle had arrived and commenced a mass application of foam. A 1-inch hand line from the second vehicle was used to attack the right wing box area that could not be reached by the foam. ARFF personnel reported that the hand line attack helped protect passengers exiting from the front portion of the airplane wreckage. About 1610, the second vehicle also exhausted its water supply.

At 1610, while these firefighting operations were in progress, a third unit, a Kovatch P-18 water supply vehicle was brought into position to resupply the other two units. Water supply lines were connected but, because of a mechanical problem, the P-18 was unable to pump any water to the other vehicles. Consequently, the P-18 was disconnected and, at 1618, Sioux City

Fire Department pumpers were positioned to replenish the two primary vehicles. By that time, the fire in the area of the right wing had intensified, spreading to the interior of the airplane. The fire intensified until approximately 1700 and was not brought under control until approximately 2 hours after the crash. Spot fires persisted throughout the night. The fire was suppressed after the application of a total of 15,000 gallons of water and 500 gallons of extinguishing agent.

1.14.2 Off-Airport Response

Following notification by the FAA control tower at 1525, the Woodbury County Communications Center in Sioux City began notifying community emergency response organizations. Community agencies included the Sioux City Fire Department (SCFD) and the Police Department, the Woodbury County Disaster and Emergency Services, and county/state law enforcement personnel. Responding units included two engine companies and a command vehicle from the fire department and an ambulance from Siouxland Health Services.

At 1534, when the control tower relayed to these units that the airplane would land about 5 miles south of the airport, the vehicles responded by traveling south of the airport on Interstate I-29. At 1538, when the fire chief learned that an attempt was being made by the DC-10 to land on runway 31, the responding SCFD units proceeded to the airport and took a position on a nearby bridge at the I-29 Sergeant Bluff exit to the airport. About 1547, the SCFD emergency responders were advised that the airplane would land on runway 31. The SCFD on-scene commander directed all units to proceed to the airport command post security staging area.

Following the crash, the SCFD assisted fire and rescue efforts. At 1625, the SCFD Fire Chief became the Site Commander. After the magnitude of the accident became apparent, the call for all available ambulances was made at 1604. Thirty four ambulances responded from more than 28 agencies, some as far away as 60 miles. Additionally, a total of nine helicopters were provided by Marian Air Care and military units from Lincoln, Nebraska, and Boone, Iowa. By 1730, all victims had been transported from the airport to the two local hospitals.

1.14.3 The Kovatch P-18 Water Supply Vehicle

When a restriction developed in the P-18's tank-to-pump hose, all water flow stopped to the two ARFF vehicles. Thus, the airport's primary firefighting vehicles could not be replenished to continue attacking the fire. The P-18's tank-to-pump suction hose assembly was removed for further examination.

The examination disclosed that the 2-inch long internal polyvinylchloride (PVC) stiffener installed in the hose had rotated laterally 90^0. Kovatch representatives stated that the internal stiffener in the soft hose assembly is required to prevent the hose from collapsing. They also stated that the stiffener was installed by a press fit in the center of the hose.

In examining the susceptibility of the internal stiffener to displace and rotate, the Safety Board found that the stiffener's length was about one-half the internal diameter of the soft suction hose. Because of the small size of the stiffener and because it was not clamped, it was free to rotate and block the flow of water or even to slide toward the pump intake, making the soft suction hose susceptible to collapse.

1.15 Survival Aspects

The largest intact section of the airplane was the center portion of the fuselage that contained seat rows 9-30 and the flight attendant jumpseats at doors 2L, 2R, 3L, and 3R. This section came to rest inverted in a corn field and was eventually destroyed by the postcrash fire. The ceiling structure collapsed throughout the fuselage, and the greatest amount of collapse was in the area of the left wing. Thirty-three of the 35 occupants who died from asphyxia secondary to smoke inhalation were in the section of the fuselage containing rows 22-30. Two other occupants in seats 14A and 16D died of asphyxia due to smoke inhalation.

The tail and a portion of the rear cabin containing 10 passenger seats and 2 flight attendant jumpseats separated early in the impact sequence. With the exception of the tail section, the cabin aft of about row 31 was destroyed by impact.

The cockpit area separated from the fuselage just aft of doors 1L and 1R and was substantially damaged, but the shoulder harnesses and lap belts remained intact and restrained the four occupants who were extricated by ARFF personnel. Most of the first class cabin section was destroyed.

1.15.1 Cabin Preparation

The flight attendants were serving a meal when the No. 2 engine failed. The senior flight attendant was called to the cockpit and was instructed by the captain to secure the cabin and prepare for an emergency evacuation. She did not ask the captain for the amount of time available until the airplane would land. In a later interview, she said that she did not request this information of the captain because she thought the flightcrew was too busy. The senior flight attendant returned to the cabin and separately instructed six of the seven flight attendants to stow food service items and to secure the cabin in preparation for an emergency landing. She related that she did not notify the passengers because she wanted to keep things "normal" as long as possible and did not want to alarm them.

The senior flight attendant related that she was told by the second officer, after he had gone to the rear of the cabin and observed damage on the tail, that the passenger briefing was going to be a "quick and dirty." [This comment refers to the abbreviated passenger briefing in lieu of a longer and more detailed briefing.] The flight attendant stated that when she received this information, the flight attendants in the aft cabin were still retrieving meal trays. Survivors related that the captain's announcement to the passengers at 1545 stated that the flight attendants had briefed the passengers about the brace position. However, the passengers had not yet been briefed about the emergency cabin preparations. The senior flight attendant began reading the "Short Notice Cabin Preparation" briefing after the captain concluded his announcement.

The Short Notice Emergency Landing Preparation directed flight attendants to be seated in their jumpseats. However, the flight attendants were standing at their demonstration positions when the briefing was read; they subsequently assisted passengers in their briefing zones. Flight attendants gave brace-for-impact instructions to parents of infants and small children. They assisted small children in passenger seats by providing pillows as padding to tighten adult lap belts. For example, a 32-month-old boy seated in 17G was given pillows to tighten his seat belt. He remained restrained during the impact sequence and was not injured.

All of the flight attendants and passengers were in a brace-for-impact position when the airplane landed.

1.15.2 Infants

There were four in-lap occupants onboard flight 232.[5] Three of them were under 24 months, and one was 26 months old. During the preparations for the emergency landing, parents were instructed to place their "infants" on the floor and to hold them there when the parent assumed the protective brace position. The four in-lap occupants were held on the floor by adults who occupied seats 11F, 12B, 14J and 22E.

The woman in 14J stated that her son "flew up in the air" upon impact but that she was able to grab him and hold onto him. Details of what happened to the 26-month-old child at 12B during the impact sequence are not known, but he sustained minor injuries. The mother of the 11-month-old girl at 11F said that she had problems placing and keeping her daughter on the floor because she was screaming and trying to stand up. The mother of the 23-month-old at 22E was worried about her son's position. She kept asking the flight attendants for more specific instructions about the brace position and her "special situation with a child on the floor." The mothers of the infants in seats 11F and 22E were unable to hold onto their infants and were unable to find them after the airplane impacted the ground. The infant originally located at 11F was rescued from the fuselage by a passenger who heard her cries and reentered the fuselage. The infant held on the floor in front of seat 22E died of asphyxia secondary to smoke inhalation. The Safety Board addressed the infant restraint issue in Safety Recommendations A-90-78 and A-90-79 issued May 30, 1990.

1.16 Tests and Research *

1.17 Additional Information *

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[5] 14 CFR 121.311 allows occupants who have not reached their second birthday to be held in the laps of an adult.

*ICAO Note.— Section 1.16 was not reproduced.

*ICAO Note.— Section 1.17 was not reproduced.

1.18 Useful Investigative Techniques

1.18.1 Special Investigative Techniques - Photograph Image Analysis

Color photographs of the accident aircraft were taken by a resident who lived on the approach path to Sioux Gateway Airport. The photographs, taken after the engine failure, depicted the damage to the right side and empennage of the aircraft. The photograph with the sharpest image was selected for further analysis. The boundaries and locations of the holes were calculated so that the locations of the holes could be incorporated into a three-dimensional scale drawing of the horizontal stabilizer. Three areas on the photograph contained four holes, which were selected for analysis: the hole on the leading edge of the right horizontal stabilizer; two holes slightly inboard and in the middle of the right horizontal stabilizer; and a hole on the right inboard elevator. The holes were defined as those areas where light could be observed penetrating areas of the stabilizer. They were transformed to the stabilizer coordinate system and input into the computer-aided design (CAD) system to generate a drawing of the horizontal stabilizer depicting the in-flight damage.

2. ANALYSIS

2.1 General

The flightcrew of UA 232 were trained and qualified in accordance with applicable Federal regulations and UAL company standards and requirements. The airplane was certificated, equipped, and operated according to applicable regulations. Meteorological conditions and navigation and communication facilities did not contribute to the accident. ATC services and controller performance were reasonable, proper, and supportive of the flightcrew and were not factors in the accident.

The Safety Board determined that the accident sequence was initiated by a catastrophic separation of the stage 1 fan disk from the No. 2 engine during cruise flight. The separation, fragmentation, and forceful discharge of uncontained stage 1 fan rotor assembly parts from the No. 2 engine led to the loss of the three hydraulic systems that powered the airplane's flight controls. The flightcrew experienced severe difficulties controlling the airplane and used differential power from the remaining two engines for partial control. The airplane subsequently crashed during an attempted emergency landing at Sioux Gateway Airport. Upon ground contact, the airplane broke apart and portions of it were consumed by fire.

The Safety Board's analysis of this accident included an evaluation of:

- o the structural and metallurgical evidence to determine the initial failure origin within the engine;
- o the manner in which uncontained parts separated from the engine;
- o the failure of the hydraulic systems that power the flight control systems;

- the capability of the flightcrew to control the airplane on its flightpath;
- the effectiveness of the GEAE CF6-6 engine manufacturing, recordkeeping, and quality assurance programs;
- the effectiveness of UAL's CF6-6 engine fan section maintenance and inspection practices;
- the effectiveness of the FAA's oversight of the design, certification, manufacture, recordkeeping, and continuing airworthiness of the CF6-6 engine;
- the effectiveness of nondestructive inspection (NDI) programs for the inspection of rotating engine parts;
- the human factors aspects of airline maintenance NDI programs;
- the design and certification of wide-bodied aircraft and jet engines to minimize damage from uncontained, rotating engine parts;
- the effectiveness of the manufacturing process for rotating engine parts made of titanium;
- cabin survivability issues, including child (infant) seat restraints; and,
- rescue and firefighting services.

2.2 Accident Sequence

Photographs of the airplane taken during the approach to Sioux City by witnesses on the ground indicated inflight damage in the area of the No. 2 engine and tail section of the airplane. The location of parts of the No. 2 engine and empennage structure near Alta, Iowa, together with the documentation and analysis of the No. 2 engine components and surrounding structure, led the Safety Board to conclude that the No. 2 engine stage 1 fan disk fracture and separation was the initial event that led to the liberation of engine rotating parts with sufficient energy to penetrate the airplane's structure.

Shortly after the engine failure, the crew noted that the hydraulic fluid pressure and quantity had fallen to zero in the three systems. Approximately 1 minute after the engine failure, the FDR recorded no further powered movement of the flight control surfaces. Consequently, the No. 2 engine failure precipitated severe damage that breached the three hydraulic systems, leaving the flight control systems inoperative.

Titanium alloy was found on the fracture surfaces of severed lines of hydraulic systems No. 1 and No. 3 located in the right horizontal stabilizer. Several of the major components of the engine, including the stage 1 fan blades and fan disk, were made from titanium alloy and no other components of the surrounding airframe were made from such material. These factors led the Safety Board to conclude that the systems' No. 1 and No. 3 hydraulic lines were severed by fragments released during the failure sequence of the No. 2 engine.

The loss of hydraulic system No. 2 required further analysis. The engine-driven No. 2 hydraulic pumps were attached to and received power from the No. 2 engine accessory section. This unit was mounted to the engine directly below the fan section of the engine. Portions of the No. 2 engine accessory section and associated No. 2 hydraulic system components, including hydraulic supply hoses, were found in the Alta, Iowa, area. Therefore, portions of the No. 2 hydraulic system and supply hoses mounted on, or adjacent to, the No. 2 engine accessory section were damaged and separated by the forces and disruption of the engine fan section during the engine failure. The investigation disclosed no evidence of other system anomalies that would have contributed to the hydraulic system or flight control difficulties experienced in the accident.

2.3 Performance of UAL 232 Flightcrew

Because of the loss of the three hydraulic systems, the flightcrew was confronted with a unique situation that left them with very limited control of the airplane. The only means available to fly the airplane was through manipulation of thrust available from the No. 1 and No. 3 engines. The primary task confronting the flightcrew was controlling the airplane on its flightpath during the long period (about 60 seconds) of the "phugoid" or pitch oscillation. This task was extremely difficult to accomplish because of the additional need to use the No. 1 and No. 3 power levers asymmetrically to maintain lateral (roll) control coupled with the need to use increases and decreases in thrust to maintain pitch control. The flightcrew found that despite their best efforts, the airplane would not maintain a stabilized flight condition.

Douglas Aircraft Company, the FAA, and UAL considered the total loss of hydraulic-powered flight controls so remote as to negate any requirement for an appropriate procedure to counter such a situation. The most comparable maneuver that the flightcrew was required to accomplish satisfactorily in a DC-10 simulator was the procedure for managing the failure of two of the three hydraulic systems; however, during this training, the remaining system was available for movement of the flight controls.

The CVR recorded the flightcrew's discussion of procedures, possible solutions, and courses of action in dealing with the loss of hydraulic system flight controls, as well as the methods of attempting an emergency landing. The captain's acceptance of the check airman to assist in the cockpit was positive and appropriate. The Safety Board views the interaction of the pilots, including the check airman, during the emergency as indicative of the value of cockpit resource management training, which has been in existence at UAL for a decade.

The loss of the normal manner of flight control, combined with an airframe vibration and the visual assessment of the damage by crewmembers, led the flightcrew to conclude that the structural integrity of the airplane was in jeopardy and that it was necessary to expedite an emergency landing. Interaction between the flightcrew and the UAL system aircraft maintenance network (SAM) did not lead to beneficial guidance. UAL flight operations attempted to ask the flightcrew to consider diverting to Lincoln, Nebraska. However, the information was sent through flight dispatch and did not reach the flightcrew in time to have altered their decision to land at the Sioux Gateway Airport.

The simulator reenactment of the events leading to the crash landing revealed that line flightcrews could not be taught to control the airplane and land safely without hydraulic power available to operate the flight controls. The results of the simulator experiments showed that a landing attempt under these conditions involves many variables that affect the extent of controllability during the approach and landing. In general, the simulator reenactments indicated that landing parameters, such as speed, touchdown point, direction, attitude, or vertical velocity could be controlled separately, but it was virtually impossible to control all parameters simultaneously.

After carefully observing the performance of a control group of DC-10-qualified pilots in the simulator, it became apparent that training for an attempted landing, comparable to that experienced by UA 232, would not help the crew in successfully handling this problem. Therefore, the Safety Board concludes that the damaged DC-10 airplane, although flyable, could not have been successfully landed on a runway with the loss of all hydraulic flight controls. The Safety Board believes that under the circumstances the UAL flightcrew performance was highly commendable and greatly exceeded reasonable expectations.

2.4 *Analysis of Fan Disk Fracture*

2.4.1 Separation of Fan Disk

Examination of the fracture surfaces of the fan disk disclosed that the near-radial, bore-to-rim fracture was the primary fracture. The fracture initiated from a fatigue region on the inside diameter of the bore. The remaining portions of the disk fractures were typical of overstress separations resulting from the fatigue failure.

Because of the geometry of the fan disk and the load paths within the disk, the near-radial fracture created a bending moment in the disk arm and web that overstressed the disk, leading to rupture and release of a segment. As soon as the segment of the disk was released, the remainder of the disk was immediately out of balance. Sufficient evidence in the form of witness marks[6] on the containment ring indicates that the segment of the disk with its blade roots still attached exited the engine around the 7:30 position. Additional evidence from the bearing housings and compressor section indicates that the remainder of the disk with attached blade roots immediately exited the engine from about the 1:00 position. Blade fragments, separately and in groups, were primarily liberated toward the right horizontal stabilizer and the aft lower fuselage area. The investigation disclosed that the liberated pieces of the engine banjo frame contained transferred titanium. However, the Safety Board could not determine which of the titanium engine parts struck the frame.

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[6] Witness marks are areas of mechanical damage or transferred material whose shape, orientation, and composition can indicate what component created the damage.

2.4.2 Initiation and Propagation of Fatigue Crack

Metallurgical examination showed that the fatigue crack initiated in a nitrogen-stabilized type I hard alpha defect at the inside surface of the bore. The hard alpha defect was formed during manufacture of the material and remained undetected through ultrasonic, macroetch, and FPI inspections performed during manufacture of the part.

Fracture mechanics evaluations performed by GEAE showed that at the time of the disk separation, the fatigue crack was of a magnitude that would cause fracture and resulting separation of the disk fan under normal loads. The number of major striations on the fatigue region was nearly equal to the total number of takeoff/landing cycles on the disk (15,503), indicating that the fatigue crack initiated very early in the life of the disk.

The results of the GEAE fracture mechanics analysis were also consistent with fatigue initiation on the first application of stress from a defect slightly larger than the size of the cavity found at the fatigue origin. The Safety Board concludes that the hard alpha defect area cracked with the application of stress during the disk's initial exposures to full thrust engine power conditions and that the crack grew until it entered material unaffected by the hard alpha defect. From that point, the crack followed established fracture mechanics predictions for Ti-6Al-4V alloy.

The Safety Board also attempted to determine the size of the fatigue crack at the time of UAL's FPI inspection of the disk 760 cycles prior to the accident. One possibility was that the discolored portion of the fatigue crack was created during the alkaline cleaning of the disk in preparation for the inspection. The fractographic examination of the fatigue region disclosed no topographic reason for the discoloration. In addition, the Safety Board is aware of no operational environment or conditions that would cause such discoloration. For these reasons, the Safety Board concludes that the discoloration on the surface of the fatigue crack was created during some step in the FPI process performed by UAL 760 cycles prior to the accident, and that the discolored area marks the size of the crack at the time of this inspection. The actual surface length of the discolored area is 0.476 inch.

The GEAE fracture mechanics analysis also was used to estimate the size of the fatigue crack at the time of the inspection. The analysis estimated that the surface length of the crack was 0.498 inch long at the last inspection.

An independent fracture mechanics analysis performed by UAL estimated a smaller crack size at 760 cycles prior to failure. However, this analysis used material properties, surface correction factors, and a load spectrum that the Safety Board believes are unrealistic.

2.4.3 Source of Hard Alpha Defect

The hard alpha defect was caused by excessive amounts of nitrogen locally situated in the material. Titanium will absorb such amounts of nitrogen only when it is in its molten state.

The vacuum-melt process has not been adequate to produce a defect-free product. Increasing the number of vacuum melts from two to three has been shown to be effective in reducing the number of defects, the source of which can be the raw material, the sponge reactor, or welded material on the electrode. However, there is always the possibility that a defect can be introduced into each melt by foreign material remaining in a furnace. Since 1971, there have been improvements in furnace cleaning requirements that are intended to reduce this problem. Tighter controls have also been placed on the raw materials for premium-grade stock (that would be made into rotating parts for aerospace uses) in an effort to ensure a higher quality product.

The current technology for quality control of titanium manufacturing has progressed to the point where critical defects are rare. Additional reductions in the number and size of defects are unlikely to occur without changing to a new production process, such as hearth melting. Major efforts associated with such a changeover are currently being evaluated to determine if hearth melting can be introduced into industrial production.

Quality assurance measures to ensure that the interior of titanium parts are defect-free are based largely on ultrasonic inspections. Such inspections have been shown to be less than 100 percent effective in detecting anomalies because detectable anomalies must be associated with cracks and voids. This accident demonstrates the difficulty of inspection. Therefore, to some extent, the engine manufacturers rely upon the billet fabrication procedures for their overall quality assurance of disk material. Although the billet producers have been constantly striving to upgrade the quality of their product, defects do occur in both double- and triple-melted material. The rupture in 1983 of a GEAE CFM-56 triple-melted stage 1 high-pressure compressor rotor disk having only 256 cycles, caused by an undetected hard alpha defect, illustrates this problem.

2.4.4 Formation of Cavity

The Safety Board believes that at the time of manufacture of the disk, the cavity at the fatigue origin point was originally filled, or nearly filled, with hard alpha material, making the defect more difficult to detect through ultrasonic means at the time of GEAE's ultrasonic inspection of the rectilinear machine forging (RMF) shape during the manufacturing process. The Safety Board also believes that the cavity was most likely created during the final machining and/or shot peening processes and that the shot peening probably created the microcracking parallel to and just below the cavity surface. Moreover, the shot peening quite likely created the mechanical deformation on portions of the cavity bottom. This mechanical deformation was inconsistent with damage that could occur during the accident sequence.

The Safety Board examined and rejected other theories concerning the formation of the cavity, including the following:

a. The cavity was originally filled with hard alpha material that fell out during or shortly after the disk separation as a result of "ringing" (severe vibrations) or damage that occurred as the disk exited the airplane. The lack of a fresh fracture appearance in portions of the cavity and the location and orientation of the microcracks beneath the cavity surface do not support this possibility.

b. The hard alpha material in the cavity was dislodged during the life of the disk, as repeated cycles of stress caused increasingly extensive cracking in the material that originally filled the cavity. However, the orientation of the microcracks beneath the surface of the cavity is more consistent with their formation by shot peening, rather than by operating stresses.

c. The cavity was never filled with hard alpha material but was part of a large void associated with the hard alpha defect. In this case, the microcracks and mechanical damage would still be produced by the shot peening, without significant enlargement of the size of the cavity. However, the hard alpha defect found in fan disk S/N MPO 00388 was approximately the same size as the defect area in the separated disk, and the two defects may have arisen from similar sources. Since the defect in S/N 388 contained no large voids, it is reasonable to conclude that the defect in the accident disk did not contain a void. Also, a void the size of the cavity should have been detected by the ultrasonic inspection of the RMF shape.

Therefore, the Safety Board concludes that the cavity was created during the final machining and/or shot peening at the time of GEAE's manufacture of the disk, after GEAE's ultrasonic and macroetch manufacturing inspections. The cavity and surrounding hard alpha material provided a stress raiser from which the fatigue crack initiated.

2.5 Origin of Accident Fan Disk MPO 00385

GEAE maintains a computerized listing of all critical rotating engine parts by part number and serial number, together with the titanium supplier's heat number, for traceability purposes. When the data for disk part number 9010M27P10 was recalled, serial number MPO 00385 was listed twice, once with heat number K8283 and once with heat number 704233. The first listing is the TIMET heat as shown on ALCOA records, and the second is a Reactive Metals Incorporated (RMI) heat number, which appeared in GEAE records only in the critical rotating parts list. ALCOA records show that RMI heat 704233 was received at ALCOA in October 1970, and remained in inventory until first cut in March 1972, 2 months after disk MPO 00385 was shipped from GEAE in an engine. The ALCOA records indicate that none of the forgings made from heat 704233 were delivered to GEAE.

Because of the discovery of contradictory records, chemical analyses were performed on the separated disk material in an attempt to verify its technical specifications and to relate the manufactured part to its basic source material. Multiple samples were removed from the bore and from the rim of each of the seven disks that records indicate were from TIMET heat K8283. In order to ensure unbiased analyses, the samples were coded before being distributed to GEAE, ALCOA, TIMET, and RMI for analysis. Results of the chemical analyses were gathered, the sample identifications were decoded, and the results distributed among the parties. In general, the chemical analyses showed that the material complied with the composition limits set forth in the applicable GEAE materials specification.

Statistical analysis of the trace element data from the chemical analyses performed by the four companies shows significant variations in some of the trace elements between the seven disks. At least two groups of disks are suggested by these analyses, and comparisons of the mean values for several elements tend to group disks MPO 00383, MPO 00384 and MPO 00387 in one cluster and disks MPO 00382, MPO 00385, MPO 00386 and MPO 00388 in another. These statistical analyses do not identify the origin of either cluster of disks, and the Safety Board cannot determine if the seven disks came from the same heat or from different heats.

However, if these disks were not produced from the same heat, the records on a large number of GEAE disks are suspect. It also means that any AD action that is based on the serial number of a disk may fail to have its intended effect because suspect disks could remain in service. For example, the AD 89-20-01 target population includes the Category I, II, and III disks, based on serial number. Because of doubts about the records, the FAA would be unable to determine whether all disks made from the billet that produced the accident disk (Category I disks) have been removed from service. Also, the priority of inspections of Category II and III disks may be inappropriate in some cases if the records do not accurately reflect the heat information, and there may be double-vacuum melted disks identified as triple-vacuum melted disks.

During the investigation, Safety Board investigators visited the ALCOA facility, inspected all available records, and viewed the forging processes in the production area. They compared stock undergoing successive forging operations and heat treatments and the records accompanying the items. They also observed heating and blocking (striking) and final forging operations in which parts were unmarked and arranged in groups on pallets. At times, they could only be identified by the accompanying "shop traveller" paperwork, which, by necessity, was separated from the parts and pallet. Because of the nature of the industrial operations conducted, identification data could be exchanged between parts in process. However, no evidence other than the chemical variances was found to indicate that any such misidentification occurred in the case of disk MPO 00385.

ALCOA keeps bulk materials in inventory at its forging facilities in order to fill customer orders more efficiently. Inventory records indicate that during the time of the manufacture of disk MPO 00385, ALCOA had argon remelted titanium billet material in stock. Its production records indicate that this material was never manufactured into GEAE parts, nor was it shipped to the GEAE facilities. Nevertheless, a stock number from some of this material (RMI heat 704233) appears in GEAE records as a source for one of the disks identified with S/N MPO 00385. No other records exist to corroborate or resolve this anomaly. In fact, all other GEAE and ALCOA records show that MPO 00385 was fabricated from TIMET heat K8283.

On July 2, 1990, GEAE issued SB 72-962, which directed a fleet campaign to verify the quality of 119 additional CF6-6 fan disks forged by ALCOA. The Safety Board has been informed that the FAA intends to issue an AD to mandate compliance with the intent of GEAE Service Bulletin 72-962. Until such time as an AD is issued, the Safety Board remains on record as recommending that the FAA mandate compliance with the Service Bulletin.

Not all records associated with the manufacture of fan rotor disks relevant to this accident were available from GEAE. The TIMET and ALCOA records indicate that the billet and forgings were manufactured and certified in accordance with the then-current GEAE specification for titanium used in rotating parts. However, several anomalies appear in the GEAE records, which call into question the reliability or accuracy of all the disk records from the same period. For instance, there were no records found indicating receipt of the fan disk forgings by the GEAE plant.

Chronologically, the first appearance of a GEAE part number 9010M27P10 for fan disk S/N MPO 00385 was on an ultrasonic inspection log sheet dated June 7, 1971, which indicates that a disk with S/N MPO 00385 was rejected and marked, "hold for investigation." There was no dispatch order card found dated in June 1971 for this serial number. Although a stock inventory card indicated that in August 1971 a CF6-6 stage 1 fan disk in the RMF shape was located in the materials lab for ultrasonic investigation, this card did not indicate a serial number. Nevertheless, a dispatch order card from GEAE records indicates that a disk with S/N MPO 00385 entered the manufacturing process on September 3, 1971, as a forging, and it passed ultrasonic inspection on September 29, 1971. This disk had a traceable record history leading to engine S/N 451-243, the No. 2 engine in the accident airplane.

A billet map prepared by ALCOA indicates that eight disk forgings, S/N MPO 00381 through MPO 00388, were made from a TIMET-supplied billet, heat number K8283. However, there were no GEAE records of any kind for a S/N MPO 00381 disk. Instead, there were two disks having S/N MPO 00385. Serialization of the disks was initiated by the forger, in this case ALCOA, from blocks of serial numbers provided by GEAE. There was no evidence at Alcoa to indicate that the company shipped two disks having S/N MPO 00385.

Additionally, GEAE and vendor correspondence records indicate that a S/N MPO 00385 disk was tested by an outside laboratory in January 1972 and that an indication of an anomoly was confirmed ultrasonically. The indication was not in the area of the bore where the defect existed on the accident disk. The disk with the ultrasonic indication was reportedly cut up by GEAE in an attempt to identify the source of the indication; no metallurgical anomalies were found. The Safety Board concludes that the outside laboratory had possession of the disk with the ultrasonic indication (as confirmed by the outside laboratory) at the time that the disk that eventually separated was receiving its final processing through GEAE. Therefore, the Safety Board believes that the two S/N MPO 00385 disks were not switched at GEAE.

The results of the chemical analyses show that disks S/N MPO 00382 through S/N MPO 00388 could have been forged from two or more billets. However, no further records were found either at GEAE or Alcoa that could confirm the origin of the material. Only limited, uncorroborated evidence suggests that the failed disk was produced from titanium not intended for use in rotating engine parts. However, if such a situation had existed, it could have contributed to the accident.

A primary purpose for lengthy retention of manufacturing and maintenance records, in addition to the certification of materials and procedures, is traceability in the event of in-service difficulties or failures. However, the records are only as useful as the thoroughness and accuracy of the persons initiating them and the system used for auditing, handling, and storing them. It appears that in the early 1970's, much of the data entry and transferral was accomplished by hand and that GEAE did not adequately audit critical parts records for accuracy. Consequently, the Safety Board concludes that the recordkeeping portion of GEAE's quality assurance program on the manufacture of CF6-6 fan disks in the early 1970's was deficient.

The Safety Board is concerned that adequate manufacturers' recordkeeping provisions may not currently be in effect. Consequently, the Safety Board recommends that the FAA conduct a comprehensive evaluation of manufacturing recordkeeping and audit procedures to ensure that adequate quality assurance and traceability of critical airplane parts can be accomplished at all manufacturing facilities.

2.5.1 Quality Assurance During Manufacturing Process

Ultrasonic and macroetch inspections were performed during the manufacturing process in 1971. The Safety Board tried to determine whether some GEAE inspection process could have or should have detected the hard alpha defect that served as the initiation point for the fatigue crack.

In the area of the bore surface of the disk, only about 0.15 inch is removed from the rectilinear machine forging shape during machining to the final shape. Since it is known that the altered microstructure surrounding the core of the hard alpha defect in the disk bore extended at least 0.273 inch aft of the center of the cavity, and for a smaller distance forward, the altered microstructure may have extended through most or all of the material removed during final machining. However, there are two reasons why the altered microstructure may not have been detectable on the rectilinear machine forged shape.

First, the material grain flow is largely parallel to the bore surface at this location. Therefore, the material segregation area would have a distinct tendency to be elongated in the direction of the grain flow, that is, in the axial direction. Because of this tendency, the radial width of the segregation area may have been much smaller than its axial length and therefore may not have extended to the surface of the rectilinear machine forged shape.

Second, some form of altered microstructure may have been detected during the inspection of the rectilinear shape, and the microstructure may have been evaluated and found acceptable, but no record of such an inspection evaluation has been found. This possibility is plausible since most of the area outside the core of the hard alpha defect contained a microstructure that, while obviously different from the matrix microstructure, was acceptable per the material specifications.

The ultrasonic inspection that was conducted on the rectilinear shape of the separated disk by GEAE in 1971 could have detected the hard alpha area only if there had been cracking or voids associated with the defect. The defect was far enough below the rectilinear shape surface that the "noise" associated with entry of the ultrasonic beam into the part would not have affected the response from the hard alpha area. Therefore, it is possible that either the hard alpha area did not have voids or cracks associated with it at that time or the inspection was performed incorrectly or inadequately.

Information available from the titanium industry indicates that virtually all the hard alpha defects that have been detected ultrasonically are associated with relatively large voids. This information is reasonable, since the presence of large voids makes detection of the hard alpha much easier by ultrasonic inspection. However, certain hard alpha defects may not be associated with large voids. This condition was demonstrated by the hard alpha defect areas found within the web of one of the sister disks, S/N MPO 00388. Detection of defects of this type would be difficult using ultrasonic inspection methods, since the change in ultrasonic attenuation at the boundary between the parent metal and the hard alpha is neither abrupt nor large.

During the metallographic evaluation of the ultrasonically located defect in disk S/N MPO 00388, significant amounts of microcracks were found associated with areas of hard alpha. It is these cracks that led to the detection of the defect areas through ultrasonic inspections conducted after the accident. Disk S/N MPO 00388 was also ultrasonically inspected during 1971, while it was in the rectilinear shape, and no indications above the rejectable limits were reported. This fact suggests that if a proper manufacturing inspection was performed, the microcracking associated with the defects in MPO 00388 was introduced into the disk after the 1971 ultrasonic inspection of the rectilinear shape. However, the ultrasonic indications generated from the recent postaccident inspection were only at the rejectable limit, and differences in the 1971 rectilinear shape inspection and the recent inspection on the final part shape make the two inspections not identical because of both procedural inspection changes over time and the alterations by final machining.

During 1971, GEAE manufacturing specifications required the disks to be macroetched in order to inspect for material segregation and other material-related defects. The etchant used by GEAE was a mixture of hydrofluoric and nitric acids in water. The disks were etched while in the rectilinear shape. Representatives of GEAE stated that the final shape of the disk was not macroetch inspected for a variety of reasons, including concern that the etching procedure would remove too much of the surface material. GEAE's current etching practice for disks is nearly identical to the practice in 1971, with the exception that a second, contrast-enhancing step has been added to the etching procedure.

Although GEAE vendors used final shape etching on fan blades, the process was not intended to detect microstructural anomalies. The Safety Board was informed during the investigation that the final shape etching process was intended to enhance the subsequent in-process inspections.

By contrast, other major turbine engine manufacturers have used a final shape etching procedure for many years. It is called blue etch anodizing (BEA), and it is used to macroetch titanium parts, including fan blades and disks. During the investigation, the Safety Board employed the BEA procedure on the pieces of the separated disk, as well as on the sister disks (the disks reportedly from the same heat as the separated disk). A comparison between the BEA procedure and the GEAE macroetching procedure showed that they were approximately equal in their capability to detect material segregation, such as was found on disk S/N MPO 00388. However, neither BEA nor an acid etch would detect a subsurface defect.

The UA 232 accident occurred because an undetected hard alpha inclusion on the surface of the disk caused initiation of a fatigue crack that eventually grew to a critical size, producing catastrophic separation of the disk. The initial hard alpha inclusion may not have been detectable using the 1971 or current ultrasonic inspection methods. In addition, the macroetching procedure that GEAE performed during the manufacturing process may not have been capable of detecting the flaw because the macroetch was performed on the rectilinear machine forged shape instead of on the final part shape. Based on the Safety Board's conclusion that the cavity was most likely created during the final machining and/or shot peening process, the Safety Board further concluded that the flaw would have been apparent if the part had been macroetched in its final part shape. The Safety Board addressed this issue in its safety recommendation A-90-91 issued June 18, 1990. (See section 4).

2.6 Operator Inspection Program and Methods

Maintenance records indicated that the stage 1 fan disk, the fan booster disk, the fan shaft, and the No. 1 bearing had been inspected in accordance with the UAL maintenance program and the GEAE CF6-6 shop manual. The records search also showed that none of the engines in which the fan disk had been installed had experienced an overspeed or bird strike. There were no items in the prior 3 months' flight records relating to the fan components.

The stage 1 fan disk records indicated that the disk had been through six detailed part inspections in its lifetime, each of which included FPI of the entire disk. All of them had been stamped and accepted by the inspectors with no crack indications observed. The last inspection was about 1 year prior to the accident. All the records examined, as well as the life history and tracking methods, appeared to be in accordance with the FAA-approved UAL maintenance program.

Based on the evaluations and contributions from GEAE, UAL, and FAA, the Safety Board believes that the GEAE predictions of crack size more closely represent actual conditions. That is, GEAE fracture mechanics predictions indicate that, at the time of the last inspection, the length of the crack was almost 1/2 inch along the bore surface.

The portion of the fatigue crack around the origin that was discolored was slightly less than 1/2-inch long along the bore surface. This size corresponds reasonably well to the size of the crack predicted by the GEAE fracture mechanics evaluation. Therefore, the Safety Board concludes that the discolored area marks the size of the crack at the time of the last inspection and that processing steps during the inspection created the discoloration.

During FPI inspection, a crack the size of the discolored region should have a high probability of detection, presuming that a proper inspection was conducted. At the time of the inspections prior to the most recent inspection in April 1988, the crack in the disk would have been much smaller. However, the GEAE fracture mechanics evaluation indicated that the surface length of the crack during several of the inspections prior to April 1988 was such that the crack would normally have been detectable by FPI. The Safety Board recognizes, however, that the unique metallurgical properties of the origin area may have altered the detectability of the crack during these inspections.

One factor that might "close" a crack and make detection more difficult is the presence of residual bulk compressive stresses. These stresses can be generated when a part is loaded so heavily that the yield stress is exceeded in local areas, resulting in permanent elongation of the metal in the stressed area. When the stress is removed, the unyielded material tries to force the yielded material to return to its original condition, resulting in a residual compressive stress on the yielded area and a residual tensile stress on the adjacent unyielded material.

Measurements on one of the sister disks revealed virtually no bulk residual stresses. Also, there is no reason to expect that the disk normally would have operated under conditions allowing stresses as high as the yield stress to be generated on the disk. Therefore, the Safety Board discounted the residual stress theory as a reason for UAL's not detecting the crack at its inspection.

UAL has asserted that it is possible for the compressive layer associated with shot peening to "close" a crack in shot peened titanium alloy, thereby preventing entry of the FPI fluid into the crack. The Safety Board is aware that shot peening or other types of mechanical work performed on the surface, if done immediately prior to inspection, may reduce or even eliminate the FPI indication. However, discussions with the FAA National Resource Specialists (for Fracture Mechanics and Metallurgy and for Nondestructive Evaluation) and other industry experts have indicated that shot peening, performed prior to cracking, has only a minimal effect on the probability of detection of a given sized flaw. In support of this contention, UAL attempted to obtain shot peened titanium engine components with large cracks that could not be detected using FPI. However, UAL personnel stated that the only components available up to the date of this report contained small cracks that, while they could be detected using eddy current inspection, were below the detectable limits of the FPI process. Further, the Safety Board possesses data indicating that FPI has long been a proven inspection method for detecting cracks on other shot peened parts. Therefore, the Safety Board concludes that the presence of shot peening on the fan disk should not have prevented the detection of the nearly 1/2-inch long crack in the disk bore at the last inspection.

Analytical procedures performed on the fracture face of the segment of the rotor disk and water washings from this surface showed the presence of di and triphenyl phosphates, compounds present in FPI fluid similar to that used to inspect the disk prior to the failure. This unique combination of chemicals shows that the crack existed at the time of this inspection and that the crack was sufficiently open so that the FPI fluid entered the crack. Based on this finding and the conclusion from metallurgical analysis that the crack was approximately 0.5 inch long on the surface of the bore of the rotor disk at the time of last inspection, the Safety Board concludes that the crack was detectable at the time of last inspection with FPI fluid. However, the crack was not detected and consequently the rotor disk was considered to be free of flaws and was accepted as a serviceable part.

A review of the inspection process suggests several explanations for the inspector's failure to detect the crack. It is possible that the inspector did not adequately prepare the part for inspection or that he did not rotate the disk, as it was suspended by a cable, to enable both proper preparation and subsequent viewing of all portions of the disk bore, particularly the area hidden by the suspension cable/hose. It is also possible that loose developer powder, which could have dropped from the suspension cable, obscured the crack sufficiently to prevent its recognition as a flaw. Finally, inspection experience indicates that certain areas of CF-6 disks, because of their geometry, frequently show large FPI indications and that other areas rarely do so. One such area of frequent indications is around the perimeter of the disk near the dovetail posts. By contrast, the central bore area apparently has rarely produced FPI indications. Thus, it is possible that the inspector did not consider the bore area a critical area for inspection, as stated in UAL's inspection directives, and that he gave the bore area only cursory attention, thereby reducing the likelihood that a crack would be detected. Any of these possibilities, or some combination of them, could have contributed to nondetection of the crack in this case.

The UAL maintenance program is comprehensive and based on industry standards. The company's inspection requirements for the CF6-6 stage 1 fan disk are generally consistent with other airline practices and comply with Federal regulations. Further, UAL's procedures for selecting, training, and qualifying NDI personnel are also consistent with industry practices. However, it is clear that the adequacy of the inspections is dependent upon the performance of the inspector. That is, there are human factors associated with NDI processes that can significantly degrade inspector performance. Specifically, NDI inspectors generally work independently and receive very little supervision. Moreover, there is minimum redundancy built into the aviation industry's FPI process to prevent human error or other task or workplace factors that can adversely affect inspector performance. Because of these and other similar factors, the Safety Board is concerned that NDI inspections in general, and FPI in particular, may not be given the detailed attention that such a critical process warrants.

The Safety Board addressed the issue of human factors in NDI inspector reliability following the Aloha Airlines B-737 accident near Maui, Hawaii, in April 1988. As a result of its investigation of the Aloha accident, the Safety Board issued two recommendations to the FAA that are relevant to the maintenance and inspection issues identified in this case.

<u>A-89-56</u>

> Require formal certification and recurrent training of aviation maintenance inspectors performing nondestructive inspection functions. Formal training should include apprenticeship and periodic skill demonstration.

<u>A-89-57</u>

> Require operators to provide specific training programs for maintenance and inspection personnel about the conditions under which visual inspections must be conducted. Require operators to periodically test personnel on their ability to detect the defined defects.

In its response to these recommendations, the FAA acknowledged that its Aging Fleet Evaluation Program has highlighted some of the same deficiencies outlined by the Safety Board and that it is addressing these issues as part of regulatory reviews of 14 CFR Parts 65 and 147. The FAA also indicated that the ultilization of inspector personnel, and the human factors aspects of such utilization, are also being examined. Based on the FAA's response, these recommendations have been classified as "Open--Acceptable Action."

The Safety Board also believes that the manual inspection systems used to inspect the vast majority of aircraft structural and engine components are inherently susceptible to human factors problems that can significantly reduce the probability of detecting a given defect. Automation of NDI is already available with current technology. Automated eddy current, ultrasonic, and FPI equipment can be employed by airline maintenance centers. The Safety Board believes that the FAA should follow through with a research program to identify emerging technologies for NDI that simplify or automate the inspection processes, provide funding to initiate demonstration programs, and encourage operators and others that perform inspections to adopt superior techniques and equipment. The FAA should also encourage the development and implementation of redundant ("second set of eyes") inspection oversight for critical part inspections, such as for rotating engine parts.

Subsequent to the Aloha Airlines accident and several other mishaps in which structural problems in high-time air carrier airplanes were identified, it became increasingly evident that the quality of maintenance ultimately depends directly on the performance of line maintenance and inspection personnel. Accordingly, the FAA has initiated a continuing series of government/industry meetings to address "Human Factors Issues in Aircraft Maintenance and Inspection."

The first of these 2-day meetings was held in October 1988, and the second was held in December 1988. The first meeting identified communication, in all its forms, as being of considerable importance in aviation maintenance and as a matter in need of attention. The second meeting focused further on issues of "information exchange and communications." A number of recommendations to the FAA resulted from these meetings in the areas of communications, training, management regulatory review, and research and development. A third meeting was held in June 1990 that focused on training issues, and additional meetings are planned by the FAA to address other aspects of the maintenance and inspection problem. FAA representatives have indicated that the results of these meetings will serve as prospective contributions to its Human Factors Research and Development program and to its regulatory review activities.

The Safety Board is encouraged by these developments and urges the FAA to continue these worthwhile efforts on an expedited basis with a view toward establishing a constructive dialogue with the key elements of the aviation maintenance community.

2.7 Philosophy of Engine/Airframe Design

2.7.1 Hydraulic Systems/Flight Control Design Concept and Certification

The three hydraulic systems installed on the DC-10 are physically separated in a manner that is intended to protect the integrity of the systems in a single-event-failure. Hydraulic fluid is isolated between the three independent systems and alternate motive systems and auxiliary systems are provided.

During the investigation of this accident, the Safety Board reviewed alternative flight control system design concepts for wide-body airplanes. The concept of three independent hydraulic systems, as installed on the DC-10, is not unique. Boeing and Airbus have three such systems on some of their most recently certified models. Lockheed and Boeing have also provided four independent systems on some of their wide-body airplanes. The Safety Board can find no inherent safety advantage to the installation of additional independent hydraulic systems for flight controls beyond those currently operating in today's fleet. However, the Safety Board believes that backup systems to the primary hydraulic systems should be developed and included in the initial design for certification. Such backup systems are particularly important for the coming generation of wide-body airplanes. Manual reversion flight control systems are quite likely impractical because of the power requirements to deflect large control surfaces that are heavily loaded. Therefore, the Safety Board recommends that the FAA encourage continued research and development into backup flight control systems that employ an alternative source of motive power.

Additional design precautions could have been taken by Douglas if the potential effect of the distribution pattern and fragment energy levels had been predicted. Engine manufacturers should provide such data to the airframe manufactures who can then incorporate measures to counter the effects into the airframe design. The problem is complicated by many factors, including the interaction of the nacelle design, engine pylon design, and supporting airframe structure.

During the UA 232 accident sequence, once the fan disk failed and the pieces began to escape the confines of the containment ring, the dispersion of rotor disk and fan blade fragments was altered by contact with both engine components and the airplane structure. The Safety Board did not attempt to determine the specific origin or trajectory of each fragment that damaged the airplane in flight. For accident prevention purposes and in the course of making safety recommendations, it was sufficient to recognize that catastrophic damage from the failure of rotating parts can originate from any fragment source with sufficient energy to penetrate the airplane's structure.

The Safety Board considers in retrospect that the potential for hydraulic system damage as a result of the effect of random engine debris should have been given more consideration in the original design and certification requirements of the DC-10 and that Douglas should have better protected the critical hydraulic system(s) from such potential effects. As a result of lessons learned from this accident, the hydraulic system enhancement mandated by AD-90-13-07 should serve to preclude loss of flight control as a result of a No. 2 engine failure. Nonetheless, the Safety Board is concerned that other aircraft may have been given similar insufficient consideration in the design for redundancy of the motive power source for flight control systems or for protecting the electronic flight and engine controls of new generation aircraft. Therefore, the Safety Board recommends that the FAA conduct system safety reviews of currently certificated aircraft in light of the lessons learned in this accident to give all possible consideration to the redundancy and protection of power sources for flight and engine controls.

2.7.2 Future Certification Concepts

On March 9, 1988, the FAA issued AC 20-128, in part as the result of a Safety Board recommendation made in 1982. The AC provides for a method of compliance with FARs that require design precautions to be taken to minimize the hazards to an airplane in the event of an uncontained engine or auxiliary power unit failure. The AC defines dispersion angles for fragments that may be released during a fan blade or rotor failure. These angles define impact areas relative to the engine installation based on recorded observations of the results of failures both in service and in tests. The AC also provides a listing of design considerations to minimize damage to critical structural elements and systems in the airplane, and defines the fragment energy levels that can be expected from the failure of a fan blade or predicted pieces of a rotor.

The Safety Board notes that the AC provides the engine/airframe designer with information that had previously been left to the interpretation of the designer. The Safety Board also notes that the initial operational capability of the high-bypass-ratio turbofan engines began in the early 1970's. For almost 20 years, and obviously during the development period of the majority of the wide-body fleet, a recognized interpretation of the regulations concerning hazards related to uncontained engine failures was not published by the FAA. The Safety Board believes that improved industry and FAA research and development programs in the area of uncontained engine failures and their effects will significantly improve the safety of the aviation fleet.

The Safety Board believes that the engine manufacturer should provide accurate data for future designs that would allow for a total safety assessment of the airplane as a whole. It is possible that in the interest of marketing a new engine to an airframe manufacturer, the engine manufacturer may underestimate the potential for failure and resultant damage. Similarly, the airframe manufacturer may not possess the data necessary to estimate the total interactive effect of the powerplant installation on the airframe.

14 CFR 25.901 paragraph (c) states: "for each powerplant and auxiliary power unit installation, it must be established that no single failure or malfunction or probable combination of failures will jeopardize the safe operation of the airplane, except that the failure of structural elements need not be considered, if the probability of each failure is extremely remote". 14 CFR 25.903 paragraph (d) (1) states: "for turbine engine installation design precautions must be taken to minimize the hazards to the airplane in the event of an engine rotor failure or of a fire originating within the engine which burns through the engine case."

14 CFR 25.901 and 25.903 are intended to bridge the gap between Part 25 and Part 33 regulations. An engine manufacturer can meet the requirements of Part 33 for an engine without regard to the airframe requirements of Part 25. The expense involved in designing, certifying, and manufacturing turbine engines requires that engine manufacturers produce engines that may be installed on several different model airplanes. Consequently, the same basic engine is usually installed on airplanes manufactured by several different companies. Each installation has its own inherent safety considerations. The differences between wing-mounted,

fuselage-mounted, and tail-mounted installations, and the number of engines present, require specific system safety assessments that are not currently explicitly required.

Although AC 20-128 provides the airframe manufacturer with a method for compliance with 14 CFR 25.903, it implies that the manufacturer should consider fragment energy levels that only the engine manufacturer can provide, and that compressor and turbine disk segment noncontainment should be considered. However, the AC does not specifically address large fan disk segments. Further, the AC is predicated on a three-piece disk rupture with only 1/3 of the disk penetrating the airplane. The Safety Board believes that in future aircraft certifications, the FAA, when assessing compliance by the airframe manufacturer with 14 CFR 25.903, should require that the engine manufacturer provide, and the airframe manufacturer consider, fragment sizes and energies such as those encountered in this accident.

In addition, in the case of large fragments, such as the fan disc segments, the spread angle or dispersion area as defined in AC 20-128 may be inadequate. This accident demonstrated inconsistancies between the predictions of AC 20-128 and the realities of the actual damage to the airframe in this accident. Also, the fact that there was titanium alloy transferred to the No. 4 banjo frame may mean that the banjo piece moved into the dispersion path. However, it may also mean that the frame was struck by the uncontained fragment of the rotor disk assembly when the fragment was oriented out of its plane of rotation by unbalanced forces during the separation sequence. If the uncontained fragment is displaced out of plane, the spread angle is then a function of the disk fragment dimensions and should be considered when showing compliance with 25.903. Therefore, the Safety Board recommends that the FAA analyze the dispersion pattern, fragment size, and energy level of released engine rotating parts in this accident and include the results of this analysis, and any other peripheral data available, in a revision of AC 20-128 for future aircraft certification.

Following this accident, the Safety Board attempted to obtain historical data and recent operating experience regarding engine rotating part failures and noncontainment events. The most recent information readily available were the two SAE reports that provided data only through 1983. The Safety Board is concerned that there may not be a central repository for a current and complete data base for engine rotating part noncontainment events. The Safety Board believes that the FAA should review the current reporting requirements for manufacturers and operators to establish a centrally available data base of these events based on operator and engine manufacturer knowledge and inservice experience.

The Safety Board recommends that the FAA establish a system to monitor the engine rotary parts failure history of turbine engines and to support a data base sufficient for design assessment, comparative safety analysis among manufacturers, and more importantly, to establish a verifiable background for the FAA to research during certification review. This system should collect worldwide data by means of the reporting requirements for manufacturers contained in 14 CFR Part 21.3.

2.8 Survival Aspects

Prelanding preparation improved the prospects of survivability for those occupants seated in areas where the fuselage remained intact.

Passengers were in protective brace positions, seatbelts were tightly fastened, and the cabin was properly secured.

With the exception of two elderly passengers who died of asphyxia from smoke inhalation, all of the occupants in rows 9-21 were able to evacuate in spite of smoke from the postcrash fire. Although most passengers were able to escape without assistance, several passengers stated that they were assisted by other passengers.

The ceiling structure collapsed throughout the fuselage; however, the greatest amount of collapse was found in the area near the left wingbox. Consequently, passengers in that section of the fuselage had less space available in which to extricate themselves from their seats and escape. Thirty three passengers in this section died of smoke inhalation: twelve of those 33 passengers had blunt trauma injuries that may have incapacitated them or slowed their escape; the other 21 persons did not sustain blunt trama injuries. Escape for those passengers seated on the left side of cabin in rows 22-30 was hampered by the hazardous combination of fuselage crush and immediate exposure to the smoke entering the fuselage. Most passengers on the right side of the cabin in rows 22-30 were able to escape because there was less crushing in that area.

The other fatalities resulted from blunt force impact injuries. These passengers were located in areas where the structural integrity of the airplane was destroyed during the impact sequence.

Current FAA regulations allow occupants who have not reached their second birthday to be held in the lap of an adult. The Safety Board believes that this regulation does not adequately protect occupants under age 2 and urged the FAA to require that infants and small children be restrained in child safety seats appropriate to their height and weight. The Safety Board believes that time consuming flight attendant duties, such as providing special brace-for-impact instructions for unrestrained infants, answering questions about those instructions, and distributing pillows in an effort to enhance the effectiveness of adult lap belts on small children, could be reduced if child restraint was mandatory. Thus, flight attendants could devote more time to other important duties while they prepare the cabin for an emergency landing. The Safety Board issued Recommendations A-90-78 and A-90-79 to address the child restraint issue on May 30, 1990. (See section 4).

When the engine failure occurred, the flight attendants were conducting a meal service. The captain contacted the senior flight attendant and instructed her to prepare the cabin for an emergency landing.

There were two types of cabin preparation contained in UAL's Land Evacuation Checklist: Full Cabin Preparation (over 10 minutes) and Short Notice Emergency Landing Preparation (under 10 minutes). Both types of preparation required the senior flight attendant to determine how much time was available prior to landing. The senior flight attendant determined to keep things "normal" in the cabin and delayed the emegency cabin preparations. Although the delay did not affect the eventual safety of passengers, the Safety Board believes that the senior flight attendant's primary goals should have been to ensure that there was adequate time to complete a full cabin preparation in the face of an obviously severe emergency. The Safety Board recommends that time management of emergency cabin preparations be reiterated in flight attendant emergency training.

2.9 Emergency Management

Overall, the established airport/county emergency plan, the recent full-scale disaster drill in 1987, and the nearly 1/2-hour of warning time facilitated the management of the emergency response. The emergency responders arrived at the scene expeditiously, established control, conducted fire suppression, and transported the injured.

The amount of agent used was appreciably more than the FAA index "B" requirements. A DC-10 routinely requires an index "D" airport under Part 139, which requires more than twice the quantity of firefighting extinguishing agents and vehicles required of an index "B" airport. Because of the large fire, the extinguishing agent was expended and the firefighters were unable to control the fire surrounding the center section of the fuselage. The Safety Board believes that the initial mass application of foam to the cabin section of the inverted fuselage facilitated evacuation of the ambulatory survivors. The Safety Board was unable to determine whether attempts by firefighters to rescue potential survivors would have been successful after the crash because of the rapidly deteriorating survival conditions.

There were several problems with the ability of the ARFF service to control the postcrash fire at the airplane's right wing root because the cornstalks and the wind direction limited the access of ARFF vehicles only to the east side of the inverted cabin. The height and density of the cornstalks also interfered with the firefighters' ability to see debris and passengers. Some of the passengers were on the ground and others were walking between the cornstalks trying to find a path leading away from the burning cabin.

Furthermore, The FAA has no guidance for ARFF operations in unique terrain, where crops can limit visibility and mobility. Considering the visibility constraints on emergency responders and terrain limitations, the FAA should reassess its policy that allows crops to be cultivated on certificated airports. The Safety Board believes that the FAA should ensure that surface obstructions, including certain agricultural crops should not be present where they might interfere with rescue and firefighting activities. A Safety Board recommendation to that effect has been addressed to the FAA. (See section 4).

When the P-18 vehicle's water pump failed during the resupply attempts, no extinguishing agent was applied to the fuselage for about 10 minutes. During this period, the fire at the airplane's right wing root intensified. Soon thereafter, the fire penetrated the cabin and resulted in deep-seated fires within the cabin that could not be reached by an exterior firefighting attack. Despite attempts to advance hand lines to the interior of the airplane, the magnitude of the fire intensified inside the cabin and burned out of control for approximately 2 1/2 hours.

The results of the examination of the P-18 pump revealed a problem with the design of the suction hose assembly. The defect caused the suction hose to collapse, blocking the flow of the water.

Tyndall Air Force Base personnel had detected the same problem in February, 1989. However, the U.S. Air Force did not take immediate action to correct this problem until after the UA 232 accident, 5 months later. There is further concern that all in-service Kovatch P-18 vehicles may not have been properly modified. Even though the Air Force is attempting to distribute modification kits for the P-18 internal hoses, there is no assurance, without an inspection and test of all units, that all the P-18's have been properly modified with the replacement hose assembly.

Of further concern is the absence of requirements for 14 CFR 139 operators to test routinely all fire-service equipment at their full-rated discharge capacity. In the absence of full-capacity testing, deficiencies in the operation of key fire/service equipment may go undetected until emergency conditions occur.

As vividly demonstrated by the UA 232 accident, all fire-service equipment should be tested at full-rated capacity prior to acceptance by the ARFF service and tested periodically thereafter. This practice would allow routine training opportunities for ARFF personnel and the opportunity to identify equipment deficiencies. Safety Board recommendations regarding emergency equipment management have been addressed to both the FAA and the Department of the Air Force. (See section 4).

2.10 Adequacy of Actions Taken Since the Accident

2.10.1 CF6-6 Fan Disk Inspection Programs

As a result of the accident, GEAE developed an ultrasonic inspection program to reverify the airworthiness of the CF6-6 engine fan disks. This inspection program was initially issued in SB 72-947 on September 15, 1989. Two revisions of SB 72-947 were issued, one in October 1989, and one in November 1989. The changes in the revisions were to expand the subject population and add disk serial numbers to the list of disks to be inspected.

SB 72-947 defined three categories of disks. Category I disks were from the heat that produced the separated disk; Category II disks were disks from heats with raw material in common with the heat that produced the separated disk (including some heats made with the triple vacuum-melting process); Category III disks were all remaining disks from heats made with the double vacuum-melting process.

Even before the pieces of separated disk were discovered in October 1989, it was believed probable that the fan disk separated as a result of material anomalies. Because material anomalies can be shared throughout a particular heat, soon after the accident GEAE began working with operators to remove from service the six remaining disks from the heat that produced the separated disk. Therefore, by the time SB 72-947 was issued, all Category I disks had been permanently removed from service.

SB-72-947 recommended that Category II disks receive an installed-engine contact-ultrasonic inspection by November 21, 1989, and an immersion-ultrasonic inspection no later than April 1, 1990. It also recommended that Category III disks receive an installed-engine ultrasonic inspection by February 4, 1990, and at intervals of 500 cycles or less, thereafter, and an immersion-ultrasonic inspection no later than December 31, 1990. On September 21, 1989, 6 days after SB 72-947 was issued, the FAA issued AD 89-20-01. In effect, this AD made SB 72-947 mandatory.

The installed-engine contact-ultrasonic inspection (per the AD and SB) is performed on the disk with only minor disassembly of engine components. This inspection is designed to be easily performed and to provide a margin of safety until the more detailed immersion-ultrasonic inspection can be performed. After a disk has been immersion-ultrasonic inspected, which requires complete disassembly of the disk from the engine, the provisions of AD 89-20-01 and SB 72-947 are met and no further ultrasonic inspections are required for the life of the disk. To amplify, GEAE stated that after the disks were immersion-inspected, the parts were considered to be equivalent to nonaffected parts.

One of the inspection modes used during the contact-ultrasonic inspection is specifically designed to detect a radial/axial crack located on the surface of the bore. This is the orientation and location of the crack that led to the separation of the accident disk. However, neither the contact nor the immersion-ultrasonic inspection mode can detect small cracks in the corner between the inside diameter of the bore and the front face of the bore. A combination of the following three factors makes this location a particularly critical one on the disk:

1. Ultrasonic inspections, by their nature, are not capable of inspecting a volume of material near the entry point of the beam.

2. The presence of the corner radius between the inside diameter of the bore and the front face of the bore makes it difficult to bring an ultrasonic probe close to this corner.

3. The area of highest stress on the disk is the forward corner of the surface of the bore. Therefore, the critical crack size is smallest at this location.

GEAE engineers have demonstrated that, using the contact-ultrasonic inspection, an axial/radial corner slot with a 0.2-inch radius (extending radially and axially a distance of 0.2 inch) generates an indication that is slightly above the rejection limit. The engineers estimated that a crack the size of the slot would grow to failure in about 650 takeoff/landing cycles. Upon initial inquiry, GEAE was unable to demonstrate how large a crack in the forward corner of the bore could be detected using the various inspection modes in the immersion-ultrasonic inspection.

Because the Safety Board was concerned that the ultrasonic inspections alone were insufficient to ensure the long-term airworthiness of the CF6-6 engine fan disks, the Safety Board issued Safety Recommendation A-90-88 to the FAA on June 18, 1990. This recommendation suggested that the FAA develop, with the assistance of GEAE, an alternate inspection method for the bore of the disks and that the FAA require that this alternate inspection be repeated at specified intervals to ensure that developing cracks are detected. (See section 4).

During meetings on Sepember 13, 1990, GEAE demonstrated that a 0.1 inch radius crack in the forward corner of the bore could be detected using one of the inspection modes in the immersion-ultrasonic inspection. GEAE estimated that a crack of this size would grow to a critical size in 1,500 cycles. GEAE stated that all Category II and III disks will be removed from service and replaced with new disks prior to the accumulation of 1,500 cycles after immersion inspection. The replacement program was initiated by the Manager of Customer Service through letter exchanges with user airlines. The Safety Board recommends that the FAA issue an AD to mandate further service limits or methods of inspection to extend residual life on disks inspected per AD-89-20-01.

Also related to CF6-6 fan disk inspections, on June 14, 1990, a few days before the Safety Board issued Safety Recommendation A-90-88, GEAE issued a revision to the CF6-6 engine shop manual, inserting provisions for an eddy current inspection of the bore area of the fan disk. Because the shop manual is a mandatory part of operators' FAA-approved maintenance programs, the eddy current inspection of the bore is required, along with an FPI of the entire disk, every time the disk is separated from the fan module.

The Safety Board believes that the eddy current inspection can detect a much smaller surface crack in the forward corner of the bore of the disk than the ultrasonic inspections. Even though the eddy current inspection is not required at specific cyclic intervals, as suggested in recommendation A-90-88, a typical disk would be expected to become a piece part and to be inspected a least several times before reaching its life limit of 18,000 cycles. Therefore, the Safety Board believes that the inclusion of the eddy current inspection in the CF6-6 engine shop manual satisfies the intent of recommendation A-90-88.

2.10.2 Hydraulic System Enhancement

The Safety Board recognizes the value of the hydraulic system enhancements for the DC-10 in the unlikely event that another DC-10 experiences similar damage to the horizontal stabilizer as a result of a No. 2 engine failure. The isolation of hydraulic system No. 3 forward of the empennage has been demonstrated through simulator testing and during actual flight tests at a safe altitude to provide acceptable limited airplane controllability. However, it must be pointed out that a leaking system No. 3 hydraulic line or component could cause the system to shut off system No. 3's hydraulic power to the empennage while system No. 1 and system No. 2 may be functioning normally. The enhancement is designed to alert the flightcrew to any isolation of system 3 if such a situation occurs.

The Safety Board notes that the incorporation of the flow rate sensing fuses on some DC-10 airplanes may provide an interim measure of safety until the installation of the electrically operated shutoff valve can be completed. Again, the Board notes that in the unlikely event of a No. 2 engine failure similar to the UA 232 accident, the fuses may provide for limited additional controllability. The design of the fuse system enhancement requires that the flow through the fuses be in excess of 15 gallons per minute. The fuses do not function at lower flow rates, and therefore the fuses will not guarantee protection against an open or breached hydraulic line if the flow is less than 15 gpm as might occur if a broken line is pinched.

In summary, the hydraulic system enhancements provided by Douglas and mandated by the FAA appear to protect the airplane in the unlikely event of a similar No. 2 engine catastrophic failure. In other failures involving the hydraulic systems and the No. 1 and No. 3 engines, the enhancements do not provide any additional margin of safety. The vulnerability of the DC-10 or other wide-bodied airplanes in the event of such failures is not known.

2.10.3 Industry Task Group Efforts

The Systems Review Task Force (SRTF) originated after the UA 232 accident. The charter of the group, as noted from an Air Transport Association memorandum to the Transport Aircraft Safety Subcommittee and FAA Research and Development Advisory Committee in December 8, 1989, stated in part:"...The charter of the SRTF is to: determine possible design concepts that will provide alternative means of control of flight critical functions in the event of total loss of all (normal) redundant systems which provide that control regardless of the probability of such loss." In addition, the SRTF was asked to consider the need for improved engine particle containment. "Where applicable, the concepts developed by the SRTF should be considered for retrofit of current fleet aircraft."

Boeing, Douglas, Airbus, Lockheed, General Electric, Pratt and Whitney, and Rolls Royce are among the airframe/engine manufacturers represented in the SRTF. Initial reports from the executive steering committee indicate that progress is continuing in all the working groups and that a final report will be available near year's end. The Safety Board supports this effort and is optimistic that the FAA will take an active role in using the committee effort to upgrade design and certification requirements.

As part of the SRTF, an Engine Containment Working Group (ECWG) is also functioning. Of interest is the group's categorization of parts that may not be contained in the event of failure. This concept states that there are parts that cannot be contained by any known means. The group's approach to this problem is to identify the potential parts in this group, to characterize their damage potential to the airplanes, and to pay special attention to them during design, in-service inspection, and repair. The group is also studying the incorporation of improved containment designs and concepts.

The ECWG is also studying inspection reliability. There are currently proposals for a joint industry/regulatory agency program to generate the probability of detection statistics for current inspection techniques and a symposium of manufacturers to address advances in containment technology.

The Safety Board has a vital interest in the work of the SRTF industry group. As evident from the UA 232 accident, inadequate predictions of secondary damage in the area of flight control redundancy have resulted in both this accident and the crash of a B-747 in Japan. There are many other wide-body-type airplanes in the world transport fleet that may benefit from a systems safety review, such as that desired by the FAA Administrator in the charter to the SRTF group. The Safety Board recommends to the FAA that the SRTF activities receive maximum encouragement and support to attain the stated objectives.

2.10.4 Damage Tolerance for Commercial Transport Engines

In addition to the separation of the fan disk involved in the UA 232 accident, there have been many examples of life-limited engine components failing before they reached their life limit. The Safety Board believes that this fact demonstrates the need for a revision of the certification, design, and maintenance philosophies for turbine engines. Currently, the certification process for rotating parts in engines assumes that the materials used are free of defects. Thus, manufacturers are not required to assume that undetectable defects are present in the material when the life of the part is calculated and demonstrated. In the case of the fan disk on the CF6-6 engine, GEAE tests conducted at the time of certification demonstrated that a defect-free disk could withstand 54,000 takeoff/landing cycles with no sign of crack initiation. This 54,000-cycle life was reduced to an FAA-approved life of 18,000 cycles.

The total number of cycles that a part experiences before failure can be divided into the number of cycles needed to initiate a crack and the cycles needed to propagate the crack to failure. For most defect-free parts, the majority of the parts' total life is in the initiation of a crack, and only a minor amount in the crack propagation phase. However, the presence of a preexisting defect in the material can effectively eliminate the initiation phase of the growth of a crack, leaving only the propagation phase to failure as residual life. This type of preexisting defect was in the fan disk involved in the UAL 232 accident. The hard alpha inclusion became a crack-like defect very early in the operation of the disk. As cycles accumulated, the crack grew larger until failure occurred before the life limit was reached.

Because of these concerns, the Safety Board, on June 18, 1990, issued recommendations A-90-89 and A-90-90 to the FAA. They recommended that the FAA require operators to incorporate a damage tolerance philosophy into the maintenance of engine components that, if the components fracture and separate, could pose a significant threat to the structure or systems of airplanes on which they are or could be installed. (See section 4).

Under a damage tolerance philosophy, it is assumed that the component material in critically stressed areas contains flaws of a size just below the flaw size detectable during manufacturing inspections. Inspection methods and intervals are thus determined by the detectable crack size per a given inspection method, the stress level at various positions within the component, and the crack propagation characteristics of the component material.

A damage tolerance philosophy has been used during the design phase for the structure of airplanes certificated after 1978. Also, older airplane models have an equivalent analysis incorporated into the maintenance of the structure through the Supplemental Structural Inspection Program, compliance with which has been made mandatory through AD's. The Safety Board believes that the FAA should begin an effort to incorporate a damage tolerance philosophy into the maintenance of certain critical components in turbine engines for commercial jet transports by investigating and defining the technological areas that need to be advanced. At the very least, the technological advances in damage tolerance assessment, nondestructive inspection, and probability calculations associated with such programs should be emphasized for use in commercial aircraft maintenance programs.

The Safety Board therefore emphasizes the need for action by the FAA and industry on recommendations A-90-89 and A-90-90.

3. CONCLUSIONS

3.1 Findings

1. The flightcrew was certificated and qualified for the flight and the airplane was dispatched in accordance with company procedures and Federal regulations.
2. Weather was not a factor in this accident.
3. Air Traffic Control services were supportive of the flightcrew and were not a factor in the accident.
4. The airplane experienced an uncontained failure of the No. 2 engine stage 1 fan rotor disk assembly.
5. No. 2 engine fragments severed the No. 1 and No. 3 hydraulic system lines, and the forces of the engine failure fractured the No. 2 hydraulic system, rendering the airplane's three hydraulic-powered flight control systems inoperative. Typical of all wide-body design transport airplanes, there are no alternative power sources for the flight control systems.
6. The airplane was marginally flyable using asymmetrical thrust from engines No. 1 and 3 after the loss of all conventional flight control systems; however, a safe landing was virtually impossible.
7. The airport emergency response was timely and initially effective; however, cornstalks on the airfield and the failure of the Kovatch P-18 water supply vehicle adversely affected firefighting operations.
8. The FAA has not adequately addressed the issue of infant occupant protection. The FAA has permitted small children and infants to be held or restrained by use of seatbelts during turbulence, landing, and takeoff, posing a danger to themselves and others.
9. Separation of the titanium alloy stage 1 fan rotor disk was the result of a fatigue crack that initiated from a type 1 hard alpha metallurgical defect on the surface of the disk bore.
10. The hard alpha metallurgical defect was formed in the titanium alloy material during manufacture of the ingot from which the disk was forged.
11. The hard alpha metallurgical defect was not detected by ultrasonic and macroetch inspections performed by General Electric Aircraft Engines during the manufacturing process of the disk.

12. The metallurgical flaw that formed during initial manufacture of the titanium alloy would have been apparent if the part had been macroetch inspected in its final part shape.

13. The cavity associated with the hard alpha metallurgical defect was created during the final machining and/or shot peening at the time of GEAE's manufacture of the disk, after GEAE's ultrasonic and macroetch manufacturing inspections.

14. The hard alpha defect area cracked with the application of stress during the disk's initial exposures to full thrust engine power conditions and the crack grew until it entered material unaffected by the hard alpha defect.

15. General Electric Aircraft Engines material and production records relevant to CF6-6 stage 1 fan disk S/N MPO 00385, which was the failed disk, were incomplete.

16. Regarding the existence at General Electric Aircraft Engines of two S/N MPO 00385 disks, an outside laboratory had possession of the disk, which was rejected for an ultrasonic indication at the time that the disk that eventually separated was receiving its final processing on the production line. Therefore, the two S/N MPO 00385 disks were not switched at the manufacturing facility.

17. General Electric Aircraft Engines disk manufacturing records and associated vendor-supplied documents, together with the system for maintaining and auditing them, did not assure accurate traceability of turbine engine rotating components.

18. United Airlines fan disk maintenance records indicated that maintenance, inspection, and repair of the CF6-6 fan disk was in accordance with the Federal Aviation Administration-approved United Airlines' maintenance program and the General Electric Aircraft Engines' shop manual.

19. A detectable fatigue crack about 0.5 inch long at the surface of the stage 1 fan disk bore of the No. 2 engine existed at the time of the most recent United Airlines inspection in April 1988 but was not detected before the accident.

20. The discoloration noted on the surface of the fatigue crack was created during the FPI process performed by UAL 760 cycles prior to the accident, and the discolored area marks the size of the crack at the time of this inspection.

21. The inspection parameters established in the United Airlines maintenance program, the United Airlines Engineering Inspection Document, and the General Electric Aircraft Engines shop manual inspection procedures, if properly followed at the maintenance facility, are adequate to identify unserviceable rotating parts prior to an in-service failure.

3.2 Probable Cause

The National Transportation Safety Board determines that the probable cause of this accident was the inadequate consideration given to human factors limitations in the inspection and quality control procedures used by United Airlines' engine overhaul facility which resulted in the failure to detect a fatigue crack originating from a previously undetected metallurgical defect located in a critical area of the stage 1 fan disk that was manufactured by General Electric Aircraft Engines. The subsequent catastrophic disintegration of the disk resulted in the liberation of debris in a pattern of distribution and with energy levels that exceeded the level of protection provided by design features of the hydraulic systems that operate the DC-10's flight controls.

4. RECOMMENDATIONS

As a result of its investigation of this accident, the National Transportation Safety Board makes the following additional recommendations:

--to the Federal Aviation Administration:

Intensify research in the nondestructive inspection field to identify emerging technologies that can serve to simplify automate, or otherwise improve the reliability of the inspection process. Such research should encourage the development and implementation of redundant ("second set of eyes") inspection oversight for critical part inspections, such as for engine rotating components. (Class II, Priority Action) (A-90-167)

Encourage research and development of backup flight control systems for newly certificated wide-body airplanes that utilize an alternative source of motive power separate from that source used for the conventional control system. (Class II, Priority Action) (A-90-168)

Conduct system safety reviews of currently certificated aircraft as a result of the lessons learned from the July 19, 1989, Sioux City, Iowa, DC-10 accident to give all possible consideration to the redundancy of, and protection for, power sources for flight and engine controls. (Class II, Priority Action) (A-90-169)

Analyze the dispersion pattern, fragment size and energy level of released engine rotating parts from the July 19, 1989, Sioux City, Iowa, DC-10 accident and include the results of this analysis, and any other peripheral data available, in a revision of AC 20-128 for future aircraft certification. (Class II, Priority Action) (A-90-170)

Conduct a comprehensive evaluation of aircraft and engine manufacturers' recordkeeping and internal audit procedures to evaluate the need to keep long-term records and to ensure that quality assurance verification and traceability of critical airplane parts can be accomplished when necessary at all manufacturing facilities. (Class II, Priority Action) (A-90-171)

Create the mechanism to support a historical data base of worldwide engine rotary part failures to facilitate design assessments and comparative safety analysis during certification reviews and other FAA research. (Class II, Priority Action) (A-90-172)

Issue an Air Carrier Operations Bulletin for all air carrier flightcrew training departments to review this accident scenario and reiterate the importance of time management in the preparation of the cabin for an impending emergency landing. (Class II, Priority Action) (A-90-173)

Issue an Airworthiness Directive to mandate service life limits or recurrent inspection requirements on GEAE CF6-6 engine stage 1 fan disks inspected in accordance with AD-89-20-01. (Class II, Priority Action) (A-90-174)

Issue an Airworthiness Directive based on the GEAE CF6-6 Engine Service Bulletin 72-962, pertaining to 119 stage 1 fan disks made from ALCOA forgings, to mandate compliance with the intent of the service bulletin by all operators. (Class II, Priority Action) (A-90-175)

--to the Air Transport Association:

Encourage member operators to incorporate specific maintenance inspection techinques in their maintenance manuals and maintenance contracts that simplify, automate, and provide redundant ("second set of eyes") inspection oversight for critical part inspection, such as for rotating engine parts. (Class II, Priority Action) (A-90-176)

--to the Aerospace Industries Association of America, Inc.

Encourage members to incorporate specific maintenance inspection techniques and inspection equipment in their service manuals that simplify, automate, and provide redundant ("second set of eyes") inspection oversight for critical part inspection, such as for rotating engine parts. (Class II, Priority Action) (A-90-177)

Also, during the course of this investigation, the National Transportation Safety Board issued the following safety recommendations to the Federal Aviation Administration:

<u>On August 17, 1989</u>

Conduct a directed safety investigation (DSI) of the General Electric CF6-6 turbine engine to establish a cyclic threshold at which the fan shaft and the fan disks should be separated and inspected for defects in the components. The DSI should include a review and analysis of:

(a) the certification, testing and stress analysis data that were used to establish the life limits of the fan disks and fan shaft components and the recommended inspection frequencies for these components;

(b) the manufacturing processes associated with the production of the fan assembly and fan forward shaft;

(c) metallurgical analysis of the front flange of the fan forward shaft in which cracks were recently discovered;

(d) the maintenance practices involved in the assembly and disassembly of the fan disks and the fan forward shaft for the potential to damage the components during these processes;

(e) nondestructive inspection of spare fan disks and fan forward shafts beginning with those components with the highest number of cycles in service; and

(f) nondestructive inspections of fan disks on installed engines that may be performed by an approved inspection procedure. (Class I, Urgent Action) (A-89-95)

Following completion of the directed safety investigation of the General Electric CF6-6 turbine engine discussed in A-89-95, issue an airworthiness directive to require appropriate inspections of the fan disks and the fan forward shaft at appropriate cyclic intervals. (Class I, Urgent Action) (A-89-96)

Evaluate, because of similarities in design, manufacture, and maintenance, the need for a directed safety investigation of all General Electric CF6-series turbine engines with the objectives of verifying the established life limits for rotating parts of the fan modules and establishing appropriate cyclic inspection requirements for these parts. (Class II, Priority Action) (A-89-97)

These recommendations were classified as "Closed-Superseded" other recommendations issued on June 18, 1990.

<u>On May 30, 1990</u>

Revise 14 CFR 91, 121 and 135 to require that all occupants be restrained during takeoff, landing, and turbulent conditions, and that all infants and small children below the weight of 40 pounds and under the height of 40 inches to be restrained in an approved child restraint system appropriate to their height and weight. (Class II, Priority Action) (A-90-78)

> Conduct research to determine the adequacy of aircraft seatbelts to restrain children too large to use child safety seats and to develop some suitable means of providing adequate restraint for such children. (Class II, Priority Action) A-90-79)

The FAA Administrator responded to Safety Recommendations A-90-78 and -79 on August 6, 1990. Regarding A-90-78, the FAA issued a Notice of Proposed Rulemaking (NPRM) on February 22, 1990, for child restraint system provisions. The Safety Board is evaluating the response.

On June 18, 1990

1) Develop, with the assistance of General Electric Aircraft Engines, an alternate method of inspecting the bore area of the CF6-6 engine fan Stage I rotor disks for the presence of surface cracks; issue an Airworthiness Directive to require that these disks be inspected with this method on an expedited basis, that disks found to have cracks be removed from service, and that the inspection be repeated at a cyclic interval based upon the crack size detectable by the inspection method, the stress level in the applicable area of the disk, and the crack propagation characteristics of the disk material. (Class I, Urgent Action) (A-90-88)

2) Evaluate currently certificated turbine engines to identify those engine components that, if they fracture an separate, could pose a significant threat to the structure or systems of the airplanes on which the engines are installed; and perform a damage tolerance evaluation of these engine components. Based on this evaluation, issue an Airworthiness Directive to require inspections of the critical components at intervals based upon by the crack size detectable by the approved inspection method used, the stress level at various locations in the component, and the crack propagation characteristic of the component material. (Class III, Longer Term Action) (A-90-89)

3) Amend 14 CFR part 33 to require that turbine engines certificated under this rule are evaluated to identify those engine components that, if they should fracture and separate, could pose a significant threat to the structure or systems of an airplane; and require that a damage tolerance evaluation of these components be performed. Based on this evaluation, require that the maintenance programs for these engines include inspection of the critical components at intervals based upon the crack size detectable by the inspection method used, the stress level at various locations in the component, and the crack propagation characteristics of the component material. (Class III Longer Term Action) (A-90-90)

4) Require turbine engine manufacturers to perform a surface macroetch inspection of the final part shape of critical

> titanium alloy rotating components during the manufacturing process. (Class II, Priority) (A-90-91)

The FAA Administrator responded to these recommendations in a letter dated July 31, 1990. The Safety Board is in the process of evaluating the response.

> On October 19, 1990
>
> Direct Airport Certification Inspectors to require 14 CFR 139 certificate holders to inspect the suction hoses on Kovatch A/S32P-18 water supply vehicles to verify that they incorporate the modifications described in Kovatch Technical Service Bulletin 86-KFTS-P-18-5 and to immediately remove from service A/S32P-18 vehicles that have not been so modified. (Class II, Priority Action) (A-90-151)
>
> Amend 14 CFR 139 to require airport operators to perform maximum capacity discharge tests of all emergency response fire fighting and water supply vehicles before the vehicles are accepted for service and on a regularly scheduled basis thereafter. (Class II, Priority action) (A-90-152)
>
> Make available to all 14 CFR 139 certificated airports an account of the circumstances of the accident described in Safety Recommendation letter A-90-147 through -155 as they relate to the deficiencies identified with the Kovatch A/S32P-18 water supply vehicle. (Class II, Priority Action) (A-90-153)
>
> Develop guidance for airport operators for acceptable responses by aircraft rescue and fire fighting equipment to accidents in crop environments on airport property. (Class II, Priority Action) (A-90-154)
>
> Require annual airport certification inspections to include examinations of airfield terrain to ensure, where practicable, that surface obstructions, including agricultural crops, do not interfere with rescue and fire fighting activities. (Class II, Priority Action) (A-90-155)

The National Transportation Safety Board issued the following recommendations to the U.S. Department of the Air Force:

> On October 19, 1990
>
> Require that Kovatch A/S32P-18 vehicles comply with Kovatch Technical Service Bulletin 86-KFTS-P-18-5 and expedite the distribution of modification kits that will permit compliance with the service bulletin. (Class II, Priority Action) (A-90-147)
>
> Immediately remove from service all Kovatch A/S32P-18 vehicles until they have been so modified. (Class II, Priority Action) (A-90-148)

> Require maximum capacity discharge tests of all emergency response fire service vehicles before the vehicles are accepted for service and on an established regular schedule thereafter. (Class II, Priority Action) (A-90-149)

> Make available to all operators of Department of the Air Force air bases an account for the circumstances of the accident described in Safety Recommendation letter A-90-147 through -150 as they relate to the deficiencies in the Kovatch A/S32P-18 water supply vehicle. (Class II, Priority Action) (A-90-150)

Member, filed the following dissenting statement on the probable cause:

> I believe that the probable cause of the accident was:
>
> (1) the manufacture by General Electric Aircraft Engines (GEAE) of a metallurgically defective titanium alloy first stage fan disk mounted on the aircraft's No. 2 engine and the failure to detect or correct the condition;
>
> (2) the failure of United Airlines to detect a fatigue crack which developed from the defect and ultimately led to a rupture of the disk and fragmentation damage that disabled the airplane's hydraulically powered fight control systems; and
>
> (3) the failure of the Douglas Aircraft Company's (Douglas) design of the airframe to account for the possibility of a random release and dispersion of engine fragments following a catastrophic failure of the No. 2 engine.
>
> Contributing to the cause of the accident was the failure of the Federal Aviation Administration's (FAA) certification process to require the DC-10 design to account for the possibility of a random release and dispersion of engine fragments following an uncontained failure of the No. 2 engine.

GEAE did not use premium grade triple-melt titanium in the manufacture of the accident disk. GEAE was at that time in the process of switching to premium grade triple-melt titanium for quality control reasons. Nevertheless, GEAE missed an opportunity to detect the hard-alpha inclusion in the accident disk when it conducted a macroetch test on metal that was to be machined away rather than on the finished fan disk.

The DC-10 was certificated in 1971. In January 1970, the FAA imposed the following Propulsion Special Condition for the DC-10:

> In lieu of the requirements of Section 25.903(d)(1), the airplane must incorporate design features to minimize hazardous damage to the airplane in the event of an engine rotor failure..."

For compliance, on July 1, 1970, Douglas Aircraft answered, in part, as follows:

> The power plants and associated systems are isolated and arranged in such a manner that the probability of the failure of one engine or system adversely affecting the operation of the other engine or systems is extremely remote.

The FAA responded that the information which Douglas provided concerning protective design features for the DC-10 satisfied the Propulsion Special Condition.

I think that the event which resulted in this accident was foreseeable, even though remote, and that neither Douglas nor the FAA was entitled to dismiss a possible rotor failure as remote when reasonable and feasible steps could have been taken to "minimize" damage in the event of engine rotor failure. That additional steps could have been taken is evidenced by the corrections readily made, even as retrofits, subsequent to the occurrence of the "remote" event.

**ICAO Note.—* Sections 1.12, 1.16 and 1.17, Figures 1, and 3 to 21, and Appendices A to D were not reproduced.

No. 6

McDonnell-Douglas DC-10-30, N54629, accident in the Ténéré desert, Niger on 19 September 1989. Report released by the Commission D'Enquête instituted by the Ministry of Transport, Niger

SYNOPSIS

Date de l'accident :

Mardi 19 septembre 1989, à 12 h 59 UTC (*).

Lieu de l'accident :

Pays : Niger ;

Localisation : 16° 54' N, 11° 59' E, dans le désert du Ténéré, au Nord-Est du massif de Termit.

Nature du vol :

Vol régulier Brazzaville-Roissy, avec escale à N'Djamena ;

Transport public de passagers, numéro du vol : UT 772 ;

Indicatif radiotéléphonique : *U.T.A. 772.*

Aéronef :

McDonnell Douglas DC-10-30 ; numéro de série : 46852 ; *immatriculation : N54629 (inscrit au registre américain).*

Propriétaire :

Interlease Incorporated (Atlanta, Georgie).

Exploitant :

Union des transports aériens (U.T.A.).

Occupants :

Personnel navigant technique : 4 ; personnel navigant commercial : 10 ; passagers : 156. Soit un total de 170.

Résumé :

L'avion décolle de N'Djamena pour Roissy à 12 h 13. Un dernier contact radio est établi à 12 h 34. L'équipage n'ayant pas rappelé au point de report prévu suivant, les procédures d'incertitude (Incerfa), d'alerte (Alerfa) et de détresse (Detresfa) sont déclenchées à partir de 14 h 30. Les recherches aériennes aboutissent tôt le lendemain matin à la localisation des débris épars de l'appareil dans le désert du Ténéré (Niger), à environ 650 kilomètres au Nord-Nord-Ouest de N'Djamena.

1. RENSEIGNEMENTS DE BASE

1.1. *Déroulement du vol*

Le mardi 19 septembre 1989, le DC-10 N54629 d'U.T.A. effectue la liaison régulière Brazzaville-Paris avec escale à N'Djamena.

L'étape Brazzaville-N'Djamena se déroule sans problème.

A N'Djamena, neuf passagers sont arrivés à destination et soixante-dix-neuf montent à bord.

L'escale de N'Djamena dure une heure.

A 12 h 13, l'appareil décolle de N'Djamena. Le plan de vol prévoit le niveau de croisière 350 (1) et le survol des points Bosso, Inisa, Djanet puis la route standard vers Paris.

A 12 h 32, cinq minutes avant l'heure prévue de passage au point Bosso, l'appareil se signale stable à son niveau de croisière.

A 12 h 34, un nouveau contact radio est établi entre N'Djamena et l'U.T. 772 qui doit rappeler à 13 h 10 au point INISA (limite des régions d'information de vol de N'Djamena et de Niamey).

Cette transmission de 12 h 34 est la dernière ; ce fait est confirmé par l'enregistrement des paramètres de vol (D.F.D.R.) et par celui des conversations et alarmes sonores en poste de pilotage (C.V.R.).

N'ayant pas reçu le compte rendu de position à INISA, le centre d'information de vol de N'Djamena tente à plusieurs reprises d'établir le contact avec le DC-10.

Sans réponse à ses appels, et n'ayant pu obtenir d'informations des centres voisins, N'Djamena déclenche à 14 h 30 la procédure INCERFA, puis à 15 h 55 la procédure ALERFA, enfin à 16 h 14 la procédure DETRESFA. La nuit tombe à 17 h 30.

Les recherches entreprises le lendemain matin permettent de localiser à 6 h 35 l'épave de l'appareil dans le désert du Ténéré, au Nord-Est du massif de Termit, sur la route prévue au plan de vol. Les débris de l'appareil sont dispersés sur une très large zone (voire annexe V).

La trajectoire de l'avion est donnée en annexe I.

1.2. *Conséquences pour les personnes*

ÉQUIPAGE		PASSAGERS enregistrés	TIERS
Tués	14	156	0
Blessés	0	0	0
Indemnes	0	0	0

1.3. *Dommages à l'aéronef*

L'avion a été totalement détruit.

1.4. *Autres dommages*

L'accident a eu lieu en zone désertique. Il n'y a donc pas d'autres dommages.

1.5. *Renseignements sur le personnel*

L'équipage technique comprenait trois pilotes et un officier mécanicien navigant. En effet, un instructeur pilote de ligne d'U.T.A. faisait subir un test en ligne au pilote en place gauche.

1.5.1. *Commandant de bord :*

Homme, quarante ans.

Brevets et licences :

- licence PL 2458 du 25 septembre 1980, validée jusqu'au 30 novembre 1989 ;
- équivalence licence US 2 345 893 du 27 avril 1989 ;
- dernière visite médicale passée le 24 novembre 1988.

Entré à U.T.A. le 4 octobre 1976.

Qualifications :

- qualification instructeur pilote de ligne ;
- *qualifications de type : DC-8, Super-Guppy,* DC-10, B-737.

Date de la qualification DC-10 : 24 novembre 1983.

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(1) 35 000 pieds soit 10 500 mètres.

(*) Les heures mentionnées dans ce rapport sont exprimées en temps universel (UTC). Il convient d'y ajouter une heure pour obtenir l'heure légale nigérienne et deux heures pour obtenir l'heure légale française en vigueur le jour de l'accident.

Expérience :

- heures de vol au total : 11 039 heures ; sur DC-10 : 2 723 heures.

1.5.2. *Pilote en place gauche :*

Homme, trente-huit ans.

Brevets et licences :

- licence PL 2833 du 23 décembre 1982, validée jusqu'au 30 novembre 1989 ;
- équivalence licence US provisoire du 21 août 1989 ;
- dernière visite médicale passée le 28 novembre 1988.

Entré à U.T.A. le 14 juin 1976.

Qualifications :

- qualifications de type : DC-8, B-747, DC-10.

Date de la qualification DC-10 : 19 août 1989.

Expérience :

- heures de vol au total : 6 442 heures ; sur DC-10 : 28 heures.

1.5.3. *Copilote :*

Homme, quarante et un ans.

Brevets et licences :

- licence PP I n° 3840 du 23 mars 1981, validée jusqu'au 31 décembre 1989 ;
- équivalence licence US 2 395 200 du 13 mai 1988 ;
- dernière visite médicale passée le 6 juin 1989.

Entré à U.T.A. le 31 décembre 1975.

Qualifications :

- qualifications de type : B-707, DC-10.

Date de la qualification DC-10 : 11 mai 1988.

Expérience :

- heures de vol au total : 8 357 heures ; sur DC-10 : 754 heures.

1.5.4. *Officier mécanicien navigant :*

Homme, vingt-huit ans.

Brevets et licences :

- mécanicien navigant n° 2669 du 19 février 1988 ;
- licence valide jusqu'au 31 juillet 1990 ;
- équivalence licence US 2 411 573 du 31 mars 1989 ;
- dernière visite médicale passée le 24 juillet 1989.

Entré à U.T.A. le 2 novembre 1988.

Qualifications :

- qualifications de type : SE-210, DC-10.

Date de la qualification DC-10 : 31 mars 1989.

Expérience :

- heures de vol au total : 597 heures ; sur DC-10 : 180 heures.

1.5.5. *Equipage commercial :*

Chef de cabine principal :
Homme, quarante-six ans ;
C.S.S. n° 3780 du 4 juillet 1968 ; validité : 31 janvier 1990 ;
Dernière visite médicale : 18 janvier 1989 ;
Entré à U.T.A. le 20 mars 1967.

Chef de cabine :
Femme, trente-trois ans ;
C.S.S. n° 9055 du 3 août 1978 ; validité : 31 mars 1990 ;
Dernière visite médicale : 24 mars 1989 ;
Entrée à U.T.A. le 11 avril 1978.

Hôtesse :
Femme, quarante-deux ans ;
C.S.S. n° 8686 du 24 août 1978 ; validité : 30 juin 1991 ;
Dernière visite médicale : 9 juin 1989 ;
Entrée à U.T.A. le 29 mars 1971.

Hôtesse :
Femme, trente-huit ans ;
C.S.S. n° 6987 du 21 août 1973 ; validité : 28 février 1990 ;
Dernière visite médicale : 1er février 1989 ;
Entrée à U.T.A. le 13 février 1973.

Hôtesse :
Femme, trente-trois ans ;
C.S.S. n° 10281 du 5 février 1980 ; validité : 31 octobre 1989 ;
Dernière visite médicale : 25 avril 1989 ;
Entrée à U.T.A. le 12 novembre 1979.

Hôtesse :
Femme, trente-sept ans ;
C.S.S. n° 7223 du 31 mai 1974 ; validité : 31 octobre 1990 ;
Dernière visite médicale : 26 octobre 1988 ;
Entrée à U.T.A. le 3 janvier 1974.

Hôtesse :
Femme, trente-neuf ans ;
C.S.S. n° 5659 du 29 décembre 1971 ; validité : 30 septembre 1990 ;
Dernière visite médicale : 7 septembre 1988 ;
Entrée à U.T.A. le 19 octobre 1971.

Hôtesse :
Femme : trente et un ans ;
C.S.S. n° 12749 du 12 novembre 1985 ; validité : 30 septembre 1990 ;
Dernière visite médicale : 9 septembre 1988 ;
Entrée à U.T.A. le 30 septembre 1985.

Steward :
Homme, trente et un ans ;
C.S.S. n° 10889 du 10 juillet 1981 ; validité : 31 janvier 1991 ;
Dernière visite médicale : 4 janvier 1989 ;
Entré à U.T.A. le 6 avril 1981.

Steward :
Homme, trente-six ans ;
C.S.S. n° 9718 du 18 mai 1979 ; validité : 28 février 1991 ;
Dernière visite médicale : 27 février 1989 ;
Entré à U.T.A. le 5 mars 1979.

1.6. *Renseignements sur l'aéronef*

Immatriculation : N54629 ;
Propriétaire : Interlease Incorporated ;
Exploitant : U.T.A.

Cellule :

Constructeur : McDonnell Douglas ;
Type : DC-10-30 ;
Numéro de série : 46852 ;
Livré neuf à l'U.T.A. en mai 1973 ;
Certificat de navigabilité numéro DAR-9-FS-EU, obtenu le 21 mars 1988 (avant cette date, l'avion était immatriculé en France) ;
Heures totales de fonctionnement : 60 267 (au 17 septembre 1989) ;
Nombre de cycles de fonctionnement : 14 777 (au 17 septembre 1989),
dont 8 378 heures et 1 779 cycles depuis grande visite.

Moteurs :

Constructeur : General Electric ;
Type : CF6-50C2R ;

Moteur n° 1 (gauche) :
Numéro de série 517493, monté sur l'avion le 30 juillet 1989 ;
29 969 heures de fonctionnement et 7 772 cycles (au 17 septembre 1989) ;
Depuis dernière révision : 468 heures et 54 cycles.

Moteur n° 2 (arrière) :
Numéro de série 455174, monté sur l'avion le 17 janvier 1989 ;
44 822 heures de fonctionnement et 12 100 cycles (au 17 septembre 1989) ;
Depuis dernière révision : 2 418 heures et 537 cycles.

Moteur n° 3 (droit) :

Numéro de série 517535, monté sur l'avion le 10 septembre 1989 ;

26 128 heures de fonctionnement et 7 271 cycles (au 17 septembre 1989).

Depuis dernière révision : 75 heures et 16 cycles.

Comptes rendus matériels (C.R.M.) :

Rien de significatif n'apparaît à l'examen des C.R.M.. L'entretien de cet avion était effectué, conformément à la réglementation en vigueur, au sein du groupe KSSU.

Masse et centrage :

La masse au départ de N'Djamena était de 187,7 tonnes dont 49,4 tonnes de carburant ; elle était dans les limites autorisées, de même que le centrage de l'avion.

1.7. *Conditions météorologiques*

1.7.1. *Situation générale en altitude :*

Au-dessus de l'Afrique (au Nord de l'Equateur), les hautes pressions subtropicales sont axées sur le parallèle 25° Nord pour la surface isobare à 500 hPa et vers le 18° Nord pour les surfaces à 300 hPa et 200 hPa.

Au sud de ces axes, entre les méridiens 10° et 20° E, les vents sont bien établis au secteur Est :

200 hPa : 080°/10 kt à 15 kt, – 55 °C à – 53 °C (du Sud vers le Nord) ;

300 hPa : 090°/10 kt, – 32 °C ;

500 hPa : 070°/15 à 20 kt, – 9 °C.

1.7.2. *Situation générale en surface :*

La zone de convergence intertropicale, matérialisée au sol par le front intertropical (F.I.T.), qui sépare les masses d'air sahariennes (air sec) des masses d'air atlantiques (air humide), se situe, dans la région du lac Tchad :

- à 12 heures, sur : 14° N – 017° E, 15° N – 010° E, 18° N – 003° E ;
- à 15 heures, sur : 14° N – 017° E, 14° N – 010° E, 17° N – 006° E.

La pénétration de la mousson n'est sensible que jusqu'aux environs du parallèle 10° N au voisinage du méridien 013° E et la couverture nuageuse ne présente aucune activité. L'enregistrement des paramètres de vol confirme que l'avion ne subit aucune turbulence.

1.7.3. *Conditions météorologiques sur le parcours :*

De N'Djamena au point 10° N – 013° E, le vol UT 772 s'effectue en conditions de ciel nuageux sans phénomène météorologique significatif :

1 à 3/8 Cu, jusqu'au dessus du lac Tchad ; bases vers 1 200/1 400 mètres, sommets 2 000 à 3 000 mètres ;

2 à 5/8 Ac, se développant au Nord du lac ; bases vers 4 000/4 500 mètres, sommets 6 000 à 7 000 mètres ;

3 à 7/8 Ci entre 7 000/8 000 mètres et 9 000/10 000 mètres.

1.7.4. *Renseignements fournis à l'équipage au départ de N'Djamena :*

Le dossier de vol retiré à 9 h 58 par l'escale d'Air Afrique et remis à l'équipage contient :

- une carte de temps significatif (TEMSI), valable pour le 19 septembre à 12 heures au-dessus du niveau de vol 250 ;
- deux cartes de prévision de vents et températures, à 300 et 200 hPa ;
- une feuille de prévision météorologique d'aérodrome (TAF) en clair de N'Djamena et de Roissy et de ses déroutements.

Sur la carte TEMSI, on note deux légères différences par rapport à la situation réelle : le tracé du F.I.T. est trop élevé de près de 5 degrés en latitude à l'Est du méridien 5° E et la zone de mousson active s'étend jusqu'au parallèle 16-17° N, soit 6 à 7 degrés trop au Nord. En fait, aucun phénomène tel que développement de cumulonimbus et turbulence forte n'était à craindre.

Pour les vents et températures en altitude, en ce qui concerne cette phase du vol, les valeurs fournies correspondent bien à la réalité (cf. § I.7.1) : le flux d'Est est régulier et faible, les valeurs de température ne présentent pas de discontinuité particulière, aussi bien en montée qu'au niveau de croisière 350, et la tropopause est au niveau 500.

1.8. *Aides à la navigation*

Le fonctionnement des aides à la navigation n'a joué aucun rôle dans cet accident.

1.9. *Télécommunications*

Les communications ont été normales jusqu'à la perte du contact bilatéral.

La transcription des radiocommunications échangées entre l'appareil et le centre de contrôle de N'Djamena fait l'objet de l'annexe 2.

1.10 *Renseignements sur l'aérodrome*

L'accident a eu lieu hors des limites d'un aérodrome.

1.11. *Enregistrement de bord*

Pour ce type d'aéronef, l'arrêté du 5 novembre 1987 (chapitre 2.11) relatif aux conditions d'utilisation des avions de transport rend obligatoire l'emport d'un enregistrement de paramètres de vol permettant la reconstitution de la trajectoire de l'avion (D.F.D.R.) et d'un enregistreur de conversations et des alarmes sonores dans le poste de pilotage (C.V.R.).

Le DC-10 N 54629 était équipé :

- d'un D.F.D.R. Sundstrand 573 A ; n° de série : 711612-1174 ;
- d'un C.V.R. Sundstrand AV 557 B ; n° de série : 6084.

Le D.F.D.R. a été retrouvé le jeudi après-midi 21 septembre dans les débris de l'épave. Il avait été endommagé par l'impact (blindage fendu). Il a été retrouvé détaché de son support.

Le C.V.R. a été retrouvé le vendredi matin 22 septembre à l'intérieur de la zone de l'impact principal, détaché de son support. Il ne semblait pas avoir été abîmé par l'impact. Son boîtier extérieur ne présentait pas de déformation apparente mais un noircissement résultant de l'incendie.

Ces deux enregistreurs ont été transportés à Paris. Ils ont été dépouillés dans la nuit du 22 au 23 septembre.

La transcription graphique des paramètres enregistrés par le D.F.D.R. est donnée en annexe 3.

1.11.1. *Exploitation du D.F.D.R. :*

Les graphiques tirés du dépouillement du D.F.D.R. montrent une grande stabilité des paramètres (vol de croisière normal au niveau de vol 350) puis, peu avant la fin de l'enregistrement, de faibles fluctuations des paramètres moteurs ainsi que des pics sur certains paramètres.

L'analyse et l'explication de ces phénomènes sont présentées au paragraphe 1.16 (recherches effectuées).

1.11.2. *Exploitation du C.V.R. :*

La bande magnétique est intacte et en bon état apparent (aspect d'une bande magnétique peu usagée). Elle ne porte ni amorce de cassure significative ni dégradations spécifiques qui auraient pu altérer sa lisibilité.

Les conversations sont audibles : jusqu'au moment de l'interruption de l'enregistrement, l'ambiance est celle d'un vol de croisière se déroulant normalement. Les communications radio sont de bonne qualité et la transcription des conversations n'a pas posé de difficulté majeure.

La datation de l'heure de l'accident a pu être faite par corrélation de l'enregistrement C.V.R. avec l'enregistrement des radiocommunications du contrôle de N'Djamena. Pour cela, la vitesse de défilement de l'enregistrement C.V.R. a été calée à l'aide d'un analyseur spectral sur la fréquence du courant alternatif de bord (400 Hz). L'accident s'est produit à 12 h 59, alors que l'équipage était en train de déjeuner tout en surveillant le bon déroulement du vol.

L'exploitation de la bande de l'enregistreur de conversations et d'alarmes sonores dans le poste de pilotage n'apporte aucun élément significatif dans le cadre de cette enquête.

La fin de l'enregistrement a fait l'objet d'une étude particulière présentée au paragraphe 1.16 (recherches effectuées).

1.12. *Renseignements sur l'épave et la zone d'impact*

Le DC-10 est tombé dans une zone désertique à relief faiblement marqué, constitué d'alternances de dunes et de thalwegs, et de zones relativement plates faiblement ondulées. Aucun point de repère n'existe à l'exception de quelques buissons d'épineux dans la partie Nord-Est de la zone de répartition des débris.

La fragmentation en vol de l'avion a été très importante : l'épave se trouve répartie sur une zone d'axe moyen 040°/220°, longue de 16 kilomètres environ en ce qui concerne les parties les plus importantes de l'avion et de 80 kilomètres environ pour les débris plus légers, soumis pendant une plus longue durée à l'action du vent.

La largeur de la zone de répartition des plus gros débris est d'environ 6 à 8 kilomètres.

Le DC-10 s'est brisé en vol en 4 grandes parties repérées A, B, C et D (voir annexe 4).

L'épave principale (repère C) se trouve dans la partie la plus au Nord-Est de la zone de répartition des débris.

A proximité se trouvent des éléments de la partie arrière du fuselage et de l'empennage (repère D) : moteur n° 2, dérive et stabilisateur droit.

A 5100 mètres au Sud de l'épave principale se trouvent le poste de pilotage et une partie de la cabine passagers (repère A).

Dans le 240° du poste de pilotage se trouvent une douzaine de grands panneaux du fuselage (repère B). Compte tenu de leur grande dispersion, ces éléments ont fait l'objet d'une recherche systématique.

Le schéma de répartition des débris est donné en annexes 5 et 6.

1.12.1. *Epave principale (repère C) :*

L'épave principale comprend les ailes, les moteurs n° 1 et n° 3 et la partie de fuselage comprise entre le cadre n° 1159 (en avant de l'emplanture de l'aile) et le cadre n° 1986.

Elle se trouve dans une zone axée Nord-Sud de 100 mètres de large sur 200 mètres de long. Elle est tombée au sol sur le dos et a brûlé en majeure partie à l'impact. Quelques éléments de la partie arrière du fuselage, dont le caisson central de stabilisateur et une partie du stabilisateur gauche, n'ont pas été détruits par le feu.

L'enregistreur de paramètres de vol a été retrouvé en limite Ouest de la zone d'incendie. Il n'a pas souffert des flammes. L'enregistreur de convervations et d'alarmes sonores se trouvait à environ 50 mètres du D.F.D.R., dans la zone calcinée. Il a été noirci par les flammes.

De nombreux corps se trouvaient encore dans cette partie de l'épave où l'incendie a été très violent.

Dans la zone de l'incendie les principaux éléments suivants ont été identifiés :

- éléments séparés du train d'atterrissage principal et du train central ;
- voilures gauche et droite avec composants désolidarisés ;
- éléments épars de becs, de volets, de capots moteurs, capots de soufflantes, réservoirs carburant ;
- porte de cabine, trappes de train ;
- moteurs n° 1 et n° 3 séparés en plusieurs modules. A l'impact au sol leurs ensembles tournants avaient une vitesse de rotation faible. Les aubes des soufflantes de ces deux moteurs présentent des traces caractéristiques d'ingestion de corps étrangers solides et sont fortement endommagées, voire brisées. Les ailettes des compresseurs sont également très endommagées. Ces dégradations ont eu lieu alors que les moteurs tournaient à régime élevé. Aucune trace de perforation des carters par des parties tournantes n'est visible.

Par ailleurs, dans la même zone, mais épargnés par l'incendie, se trouvaient les éléments suivants :

- partie inférieure de l'arrière du fuselage ;
- caisson central du stabilisateur ;
- partie du stabilisateur gauche ;
- section arrière du fuselage avec des éléments du groupe auxiliaire de puissance (APU) ;
- porte de soute arrière (fermée et verrouillée) ;
- fond de la soute arrière.

La position et la répartition des éléments énumérés ci-dessus confirment que la partie de l'avion comprise entre l'emplanture des ailes et l'avant de l'empennage a percuté le sol en un seul bloc en position dos.

1.12.2. *Poste de pilotage et partie avant de la cabine (repère A) :*

La partie avant du fuselage se trouve par 16° 54′ N et 011° 59′ E dans le 187° et à environ 5 kilomètres de l'épave principale.

Elle repose au sol sur le flanc droit et elle n'a pas brûlé. Les corps des pilotes, de l'officier mécanien et d'un steward s'y trouvaient encore.

1.12.3. *Partie arrière du fuselage-empennage (repère D) :*

La partie arrière du fuselage, brisée au voisinage du cadre 1986, s'est rompue en l'air en plusieurs éléments comprenant :

a) La section avant de la manche d'entrée d'air du moteur n° 2 ;

La section arrière de cette manche d'entrée d'air et une partie importante de la dérive ;

La partie supérieure de la dérive ;

Le drapeau de gouverne de direction ;

Des éléments de structure secondaire et de capotage du moteur n° 2.

Le bord d'attaque de la dérive comporte des traces d'impacts de pièces métalliques survenus au cours de la rupture en vol de l'aéronef.

b) Le moteur n° 2, séparé de la structure avant d'atteindre le sol. Avec sa tuyère, il constitue la partie située le plus au nord de l'ensemble des éléments cités ci-dessus.

Les dommages subis par ce moteur résultent directement de l'impact au sol. L'examen visuel montre que les parties tournantes avaient alors une vitesse de rotation faible. Certaines marques sur les aubes de la soufflante montrent qu'il y a eu ingestion de corps étrangers alors que le régime de rotation était élevé.

Aucune trace de perforation du carter par des parties tournantes n'est visible.

Tous les éléments cités en *a* et *b* se trouvent à environ 1 kilomètre dans le 080° de l'épave principale.

c) Le stabilisateur droit, dont le bord d'attaque présente des traces d'impacts similaires à celles relevées sur la dérive, est situé dans le 230° de l'épave principale, à 2,3 kilomètres.

Aucun de ces éléments n'a brûlé.

1.12.4. *Partie avant du fuselage – soute avant (repère B) :*

Le tronçon de fuselage compris entre les éléments repérés A et C comporte la soute avant et une partie de la cabine passagers. Sur un avion intact, c'est un cylindre de 14 mètres de long. Il s'est fragmenté en une douzaine de grands panneaux, retrouvés dans une zone de 8 kilomètres de longueur et de 6 kilomètres de largeur. Le centre de cette zone se trouve approximativement dans le 237° à 7 kilomètres du poste de pilotage, et son axe moyen est orienté 045°/225°.

La partie la plus importante de ces éléments est constituée d'un panneau comprenant 12 hublots et la porte de soute avant. La porte de soute, qui se trouvait sur le côté droit du fuselage, est encore en place, fermée et verrouillée.

Ce panneau est situé approximativement entre les cadres n^os^ 824 et 998/1019.

Il a été localisé à 3,3 kilomètres dans le 200° du poste de pilotage.

Entre ce dernier point et la partie la plus sud-ouest de la zone se trouvaient les autres éléments les plus importants de cette section de fuselage :

- un panneau situé entre les cadres n^os^ 999 et 1099 et comportant 4 hublots entiers, le phare d'atterrissage gauche et le phare d'éclairage du bord d'attaque de l'aile gauche ;
- un panneau de 3 mètres sur 5 mètres environ, situé approximativement entre les cadres n^os^ 755 et 879, com-

portant l'encadrement inférieur de la porte n° 12 (côté gauche du fuselage), le panneau d'alimentation en eau de l'aéronef et les prises statiques. Ce panneau présente des traces très nettes de perforation par un ou plusieurs éléments provenant de l'intérieur.

Les feuilles d'étanchéité présentent des déformations caractéristiques créées par une forte surpression à l'intérieur du fuselage.

Dans cette zone ont été également trouvés :

- des morceaux de revêtement du fuselage de diverses dimensions, séparés de la structure ;
- des morceaux de structure (cadres et lisses non revêtus) d'environ 1,50 m × 1 m ;
- des éléments de structure du plancher cabine ;
- des éléments de conteneur ainsi que des équipements électriques et des équipements de cabine (sièges, offices, chariots, coffres à bagages, chauffe-eau, etc.) ;
- de nombreux bagages et vêtements.

Aucun des éléments trouvés dans cette zone n'a brûlé.

La majorité des débris de fuselage de cette section (cadre 595 à 1099) ont été récupérés et rassemblés. L'ensemble ainsi retrouvé représente environ 90 p. 100 de la partie fragmentée de l'appareil.

1.12.5. *Entrée d'air moteur 1. - Toboggan :*

Entre l'épave principale et un point situé approximativement dans le 220° et à 9,2 kilomètres de cette épave ont été retrouvés du Sud vers le Nord :

- l'entrée d'air du moteur n° 1, dont les lèvres présentent des traces d'impact ;
- un toboggan ;
- des éléments de volets et de becs de bord d'attaque.

1.12.6. *Eléments légers :*

La plupart des éléments les plus légers de l'aéronef (panneaux de décoration de cabine en matière composite, papiers, etc.) ont été soumis à l'action du vent et disséminés dans une zone large de 10 kilomètres à 15 kilomètres et longue d'environ 50 kilomètres au Sud de la zone décrite en 1.12.4.

Au cours des recherches effectuées par avion et hélicoptère, il n'a pas été retrouvé d'éléments importants de l'aéronef parmi ces éléments légers.

1.12.7. *Indices particuliers :*

Au voisinage de la zone de recherche définie ci-dessus (zone dans laquelle se trouvent les fragments de la partie B de l'avion), et plus précisément autour d'un point situé à 7,5 kilomètres et dans le 245° du poste de pilotage, ont été trouvés :

- des morceaux de conteneur et de plancher de soute dont les uns présentent des traces caractéristiques d'explosion (petits cratères avec fusion de métal) et les autres présentent des déformations ne pouvant pas résulter du choc avec le sol ;
- des morceaux de caisses en bois criblés d'éclats métalliques ;
- des vêtements lacérés et troués ainsi que des fragments de bagages déformés et brûlés par endroits.

D'après le plan de chargement, ces objets se trouvaient dans la soute avant de l'appareil.

Leur présence parmi des débris qui n'ont pas brûlé ne peut s'expliquer que par une explosion survenue en vol. Les examens et analyses faits en laboratoire dans le cadre de l'enquête judiciaire ont mis en évidence de fortes traces de matière explosive (penthrite), notamment sur un fragment de valise. Il a pu être établi que la quantité d'explosif était au minimum d'un kilogramme.

1.13. *Renseignements médicaux et pathologiques*

Lors de la rupture de la cellule survenue à très haute altitude, les occupants du DC-10 ont subi instantanément, outre l'onde de choc due à l'explosion, une dépressurisation brutale, un refroidissement très rapide (température ambiante extérieure de l'ordre de - 45 °C) et un manque d'oxygène entraînant une perte de conscience immédiate.

1.14. *Incendie*

L'incendie de la partie principale de l'épave est la conséquence de l'impact au sol, le feu étant alimenté par le carburant de l'avion.

1.15. *Questions relatives à la survie des occupants*

1.15.1 *Survie des occupants :*

Cet accident ne laissait aucune chance de survie aux occupants de l'appareil.

1.15.2. *Déclenchement des phases d'urgence :*

L'appareil décole de N'Djamena à 12 h 13. Il estime le point Bosso à 12 h 37, la limite de F.I.R. N'Djamena-Niamey (point INISA) à 13 h 10 et la limite de F.I.R. Niamey-Alger (point KIRMI) à 13 h 40.

Le dernier contact avec les services du contrôle au sol a lieu aux environs de 12 h 34 sur la fréquence 128.1 MHz lorsque l'équipage du DC-10 annonce au centre d'information de vol de N'Djamena qu'il va passer le point Bosso. Le contact suivant, toujours avec N'Djamena, devait avoir lieu sur la fréquence HF 8903 kHz vers 13 h 10. Entre 12 h 34 et 12 h 36, l'équipage effectue un relais radio avec un autre avion pour le C.I.V. de N'Djamena.

L'équipage du DC-10 ne rappelant pas à l'heure estimée du passage de F.I.R., les contrôleurs des C.I.V. de N'Djamena et Niamey lancent plusieurs appels SELCAL sur la fréquence 8903 kHz.

Les centres de Kano et Alger interrogés ne peuvent fournir d'éléments sur ce vol. Avec certains des centres susceptibles de donner des nouvelles, les liaisons radio sont établies difficilement.

Les messages déclenchant l'INCERFA (*) et l'ALERFA (*) sont émis respectivement à 14 h 30 et à 15 h 55.

A 16 h 14, le message DETRESFA (*) est émis et le centre de coordination de sauvetage de N'Djamena prépare la mise en place des opérations de secours. La nuit tombant vers 17 h 30, les recherches aériennes commencent le lendemain, avec le décollage d'un Transall de l'armée de l'air française à 4 h 15. L'épave est repérée à 6 h 35.

1.15.3. *Balise de détresse :*

La réglementation en vigueur ne l'imposant pas, le DC-10 n'était pas équipé d'une radio-balise de détresse fonctionnant automatiquement à l'impact (RDBA).

Le centre de contrôle de mission SARSAT/COSPAS, à Toulouse, a cependant été interrogé par N'Djamena à 17 h 22 mais n'a pu évidemment fournir de localisation.

1.16. *Recherches effectuées*

Du 20 au 23 septembre 1989, les enquêteurs ont porté leur attention successivement sur la récupération des enregistreurs, sur l'état des moteurs, sur la fermeture des portes de soute et sur la répartition générale des débris de l'avion. Cette dernière observation les a conduits à constater la dispersion de la partie B de l'avion en une douzaine de fragments, alors que les parties antérieure (A) et postérieure (C) étaient tombées entières au sol. Au cours de cet examen, les indices particuliers décrits en 1.12.7 ont été trouvés.

(*) En espace aérien non contrôlé, la phase d'incertitude (INCERFA) doit être déclenchée lorsque deux messages consécutifs obligatoires n'ont pas été reçus.

La phase d'alerte (ALERFA) est déclenchée quarante-cinq minutes après le déclenchement de la phase d'incertitude.

La phase de détresse (DETRESFA) est déclenchée quarante-cinq minutes après le déclenchement de la phase d'alerte.

En conséquence, les enquêteurs ont décidé de concentrer rapidement leur action sur la recherche et la récupération des débris provenant de cette partie B, avant que le vent de sable ne rende la recherche plus difficile.

Une opération de ratissage d'un rectangle de désert de 10 kilomètres sur 6 kilomètres a été effectuée le 27 septembre par seize enquêteurs civils, une trentaine de militaires nigériens et une trentaine de parachutistes français, avec quatre hélicoptères de l'armée de terre (Alat) et des camions tout terrain. La sécurité et la couverture radio de l'ensemble de l'opération étaient assurées par un Bréguet-Atlantic de l'aéronautique navale.

Ce ratissage a permis de récupérer environ 90 p. 100 de la structure de la partie B ainsi que divers objets portant la trace d'une explosion. Les morceaux récupérés ont été transportés par camions à N'Guigmi (350 kilomètres), puis par avion Transall de l'armée de l'air française à Niamey et par avion U.T.A. à Paris.

Réunie le 9 octobre 1989, la commission d'enquête a élaboré son rapport préliminaire, qui se termine par la conclusion suivante : « Une explosion a eu lieu dans la soute avant et a entraîné la destruction de l'avion. »

La commission a également défini le programme des recherches complémentaires à effectuer :

Il a été convenu de faire reconstituer la partie B du fuselage afin de localiser le plus précisément possible le foyer de l'explosion et de décrire le processus de rupture du fuselage ;

Il a été décidé de faire mener une étude particulière sur la fin des enregistrements D.F.D.R. et C.V.R. ;

Enfin, il a été décidé, en se référant à l'annexe 17 de la Convention sur l'aviation civile internationale (1), d'examiner les mesures de sûreté qui ont été mises en œuvre au bénéfice du vol 772.

1.16.1. ***Reconstitution de la partie B du fuselage :***

Les débris récupérés dans le désert du Ténéré comprenaient de grandes parties du revêtement de fuselage, des morceaux du plancher de la soute avant, des conteneurs (ou morceaux de conteneurs) ainsi qu'une palette.

Ces débris ont été déposés dans un hangar de la base aérienne militaire de Dugny (aérodrome de Paris-Le Bourget). Les opérations de reconstitution du segment de fuselage ont été réalisées par les techniciens de la compagnie U.T.A. Elles ont nécessité au préalable la construction d'un bâti capable de supporter les quinze tonnes de métal constituant le tronçon de fuselage.

Les premiers travaux ont eu pour but d'identifier les différentes parties du fuselage, du plancher de soute et des conteneurs. Cela a été fait en les juxtaposant sur le sol.

Les éléments de la structure ventrale ont été ensuite placés sur le bâti, puis les éléments des flancs gauche et droit, y compris la porte de soute avant.

La partie supérieure du tronçon de fuselage a fait l'objet d'un examen attentif. Ne présentant pas d'intérêt particulier pour l'enquête et pour la compréhension du processus de rupture du fuselage, elle n'a pas été montée sur le bâti. Ses composants ont été juxtaposés à même le sol du hangar.

1.16.2. *Localisation de la charge explosive :*

L'examen du tronçon de fuselage reconstitué montre que l'explosion a provoqué dans la cellule trois ouvertures principales, situées dans un plan vertical qui fait un angle d'environ 50° avec l'axe longitudinal de la cellule (voir annexe 7). Cette constatation évoque une propagation des effets destructeurs de l'onde de choc selon des cônes schématisés en annexe 7 et donne une position présumée du foyer de l'explosion.

Les ouvertures dans le fuselage (voir annexes 8 *a*, 8 *b* et 8 *c*) ont été causées par l'effet de souffle provoquant une surpression intense, associée à la projection sur les parois du matériel que contenait la soute. Ce matériel (bagages, conteneurs, palettes) a été disloqué, fragmenté et projeté avec une grande énergie.

Les dommages constatés sur le flanc droit de l'avion sont les plus importants. Ils coïncident avec les dégâts constatés sur le plancher de soute et sur les conteneurs placés du même côté. Les dommages constatés sur le flanc gauche résultent des efforts mécaniques de l'explosion suivant l'axe du cône.

Des photos de la reconstitution du fuselage sont données en annexe 8.

L'examen des conteneurs et la mise en coïncidence de leurs déformations avec celles du plancher de soute (annexe 8 *d*) et du revêtement de fuselage montrent que l'explosion a eu lieu dans le conteneur n° 7044 RK (1). Ce conteneur se trouvait en place 13-droite (13-R sur le plan de chargement, cf. annexe 7), ce qui corrobore les observations rapportées plus haut.

Seuls des bagages enregistrés à Brazzaville à destination de Paris étaient à l'intérieur de ce conteneur. Il n'était pas accessible pendant l'escale à N'Djamena.

1.16.3. *Processus de rupture :*

Le processus de rupture de la partie avant de l'avion a été trop complexe pour pouvoir être décrit de manière précise et détaillée. Cependant, l'examen des cassures permet de dire que le cockpit s'est replié sur la partie gauche du fuselage.

Les ruptures du fuselage sont de trois types :

- celles qui affectent les lignes de rivetage soit à des raccordements de panneaux, soit en « pleine peau », selon la direction de l'axe principal du fuselage ;
- celles qui parcourent les panneaux de revêtement selon un dessin faïencé avec épanouissement vers l'extérieur ;
- celles qui affectent les pièces les plus massives et les bordures des deux parties restées plus cohérentes (jonctions de la partie B avec le poste de pilotage et avec le tronçon central).

Ces dernières ruptures ne paraissent pas dues à l'effet direct de l'explosion, mais plutôt à un processus d'arrachement provoqué par des efforts aérodynamiques importants.

L'état de certains morceaux de panneaux de fuselage (aspect froissé sur de larges zones) est significatif d'un écrasement des parties fragilisées consécutif aux mécanismes de désolidarisation de la partie avant de l'avion.

L'absence d'éléments du plancher de la cabine ou du plafond de soute avant ainsi que des habillages intérieurs s'explique par la légèreté de ces éléments (nid d'abeille et structure feuilletée). Leur fragmentation et leur dispersion sous l'effet du vent au cours de la chute ont été importantes.

En résumé, le processus de destruction a été assez complexe ; il a eu probablement une durée plus longue que le simple passage d'une onde de choc.

1.16.4. *Etat de la cellule :*

L'examen détaillé du segment de fuselage lors des travaux de reconstitution ainsi que les observations faites sur le lieu de l'accident permettent de dire que la cellule du DC-10 était en très bon état ; en particulier, elle ne présentait aucune trace de corrosion.

1.16.5. *Analyse de la fin de l'enregistrement D.F.D.R. :*

On a vu en 1.11.1 qu'apparaissent, peu avant la fin de l'enregistrement D.F.D.R. :

- de faibles fluctuations des paramètres moteurs (cf. annexe 3, courbes 1) ;
- des pics aberrants sur certains autres paramètres (cf. annexe 3, courbes 2).

1.16.5.1. Analyse des fluctuations des paramètres moteurs :

Quelques minutes avant la fin de l'enregistrement des conversations, les pilotes parlent entre eux des modalités de réglage des « speed bugs » (index de vitesse).

On sait qu'un léger déplacement de ces index entraîne automatiquement un réajustement des paramètres moteur par l'automanette.

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(1) Annexe 17. - Protection de l'aviation civile internationale contre les actes d'intervention illicite.

(1) A l'époque de l'accident, le parc des conteneurs des compagnies U.T.A. et Air Afrique (RK) était banalisé.

Les fluctuations constatées des paramètres moteurs sont corrélées avec la discussion des pilotes, qui devaient faire en parlant de légers ajustements sur les « speed bugs ».

1.16.5.2. Analyse des pics observés sur certains autres paramètres :

Les valeurs aberrantes qui affectent certains paramètres quelques secondes avant la fin de l'enregistrement D.F.D.R. pouvaient donner lieu à toutes sortes de questions ou de supputations.

Il importait donc d'en faire une analyse rigoureuse et précise, et d'en donner l'explication.

Cette étude fine a été faite par les spécialistes du bureau enquêtes-accidents. Elle est donnée en annexe 3 au présent rapport.

Elle démontre que les valeurs aberrantes constatées ne proviennent pas de variations des grandeurs physiques enregistrées, mais de difficultés de lecture de la bande, qui a été fortement endommagée en plusieurs endroits lors du choc provoqué par l'impact au sol du D.F.D.R. Ces dégradations ont provoqué des désynchronisations du signal fourni par l'enregistreur lors du dépouillement. Quant aux grandeurs physiques enregistrées, elles avaient les valeurs et la stabilité correspondant à un vol en croisière normal au niveau 350.

1.16.6. *Analyse de la fin de l'enregistrement C.V.R. :*

Outre la transcription des conversations, des études ont été faites sur la fin de l'enregistrement afin de rechercher des indices éventuels de bruit d'explosion.

L'analyse spectrale du transitoire final a révélé une onde vibratoire générée par l'explosion et transmise par la structure de l'aéronef. Aucune trace d'onde de choc transmise par voie aérienne n'a été mise en évidence.

1.17. *Investigations complémentaires*

Les recherches relatées dans le paragraphe 1.16 ont conduit à constater que :

- l'explosion a eu lieu dans un conteneur situé en soute avant, en place 13-droite (13-R), cf. annexe 7 ;
- ce conteneur, chargé en soute à Brazzaville, ne contenait que des bagages enregistrés à Brazzaville à destination de Paris ;
- la porte de ce conteneur, tel qu'il était placé en 13-R, ne pouvait pas être ouverte pendant l'escale à N'Djamena. Il aurait fallu, pour l'ouvrir, déplacer au préalable le conteneur en cause ainsi que celui qui le séparait de la porte de soute (place 14-R). On ne peut pas considérer comme plausible l'hypothèse que cette double manipulation ait été faite sans attirer l'attention de quiconque pendant l'escale d'une heure, de jour, à N'Djamena.

La commission a donc retenu comme hypothèse la plus plausible celle d'une charge explosive placée dans un des bagages embarqués à Brazzaville à destination de Paris.

Pour protéger le transport aérien contre de tels attentats, pour définir le niveau nécessaire et raisonnable des mesures de sûreté à mettre en œuvre sur les aéroports, des normes et des pratiques recommandées sont prescrites par l'une des annexes (1) à la convention relative à l'aviation civile internationale, ainsi que par les éléments indicatifs du Manuel de sûreté de l'aviation civile de l'O.A.C.I. (DOC/8973).

Se référant à ces textes, la commission a considéré qu'elle devait, aux termes de son mandat, s'informer sur les mesures de sûreté qui étaient mises en œuvre sur l'aéroport de Brazzaville, à l'époque de l'accident, au bénéfice des vols internationaux en partance. Elle a donc pris connaissance des principales constatations faites en octobre 1989 par les experts français envoyés en mission sur ce sujet auprès des autorités congolaises compétentes :

a) Dans l'aérogare, l'enregistrement des passagers et des bagages au départ de vols internationaux et de vols domestiques pouvait se faire simultanément dans la même zone. La circulation des personnes et des bagages entre zone publique et zone réservée n'était pas suffisamment réglementée et contrôlée. En particulier, le tapis roulant collecteur des bagages enregistrés était facilement accessible.

Plus généralement, les dimensions de l'aérogare, inadaptées au nombre des passagers et de leurs accompagnateurs lors de plusieurs départs simultanés, rendent assez aléatoire la mise en œuvre de contrôles rigoureux.

b) Sur la demande d'un passager, il était possible de faire, la veille du départ, à l'hôtel, un préenregistrement des bagages de soute. Entre ce préenregistrement et le chargement à bord de l'avion, les bagages passaient environ douze à vingt-quatre heures sur l'aéroport dans un conteneur qui ne bénéficiait pas d'une protection et d'une surveillance suffisantes.

c) Un passager pouvait faire enregistrer ses bagages par l'un de ses employés. Cette pratique (appelée couramment « l'enregistrement-protocole ») n'excluait pas la possibilité d'une substitution de bagage (ou d'une adjonction de bagage), à l'insu du passager.

d) A titre d'ultime précaution, au terme des opérations d'enregistrement, une mesure de sûreté efficace est la reconnaissance des bagages de soute par les passagers, au moment de l'embarquement, au pied de l'avion. Cette mesure n'était pas mise en œuvre à Brazzaville à l'époque de l'accident.

En conséquence, les trois hypothèses suivantes peuvent être considérées comme plausibles :

- bagage muni frauduleusement d'une étiquette d'enregistrement à destination de Paris et déposé soit sur le tapis collecteur de bagages, soit dans le conteneur qui regroupe temporairement les bagages préenregistrés ;
- bagage accepté par un passager dupe, ou enregistré à l'insu du passager en profitant d'un « enregistrement-protocole » ;
- bagage enregistré par un passager qui débarque à N'Djamena, alors que sa destination (et donc celle du bagage) est Paris.

Dans les deux dernières hypothèses, il faut supposer, en outre, que l'engin explosif est dissimulé dans le bagage de telle sorte qu'il échappe à l'inspection manuelle des bagages (cette inspection est faite immédiatement avant l'enregistrement).

Au sujet de la troisième hypothèse, la commission a pris connaissance des observations faites par les mêmes experts français à N'Djamena, en octobre 1989, sur un point important : était-il possible qu'un passager Brazzaville-Paris débarque, lors de l'escale de transit, sans être remarqué ? Réponse : cette hypothèse ne peut pas être écartée, en dépit de la surveillance, par la police tchadienne des frontières, des passagers débarquant.

Les experts français ont aussi appris, lors de leur mission à N'Djamena, que, le 19 septembre, pendant l'escale d'une heure, le DC-10 a été constamment surveillé par trois gardiens en armes et que les diverses personnes ayant eu à intervenir sur l'avion se connaissaient. Cela confirme l'hypothèse retenue par la commission (charge explosive embarquée à Brazzaville).

2. ANALYSE ET CONCLUSIONS

Le DC-10 effectuant le 19 septembre 1989 le vol U.T.A. 772 (Brazzaville-N'Djamena-Paris) a été détruit par une explosion, quarante-six minutes après son départ de N'Djamena, alors qu'il volait en croisière au niveau 350 dans des conditions tout à fait normales.

Cette destruction a été provoquée par une charge explosive placée dans un conteneur situé en place 13-droite dans la soute avant.

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(1) Annexe 17. - Protection de l'aviation civile internationale contre les actes d'intervention illicite.

La commission d'enquête considère comme l'hypothèse la plus plausible que cette charge explosive était contenue dans un bagage chargé à Brazzaville.

Les constatations faites peu après l'accident sur l'aéroport de Brazzaville montrent qu'à cette époque les mesures de sûreté appliquées sur cet aéroport n'étaient pas conformes aux normes et pratiques recommandées de l'O.A.C.I. (annexe 17 à la convention sur l'aviation civile internationale et Manuel de sûreté de l'aviation civile internationale (DOC 8973).

3. RECOMMANDATIONS

3.1. Le 4 octobre 1989, sur la proposition conjointe de la délégation nigérienne et de la délégation française, l'assemblée générale de l'O.A.C.I. a adopté une résolution A-27-9 sur les actes d'intervention illicite visant à provoquer la destruction d'aéronefs civils en vol.

Après avoir condamné énergiquement les actes criminels commis contre les avions de transport civil, cette résolution :

- demande instamment aux Etats d'intensifier leurs efforts pour mettre en œuvre les normes, pratiques recommandées et procédures prescrites par l'O.A.C.I. en matière de sûreté, et de prendre des mesures additionnelles appropriées chaque fois que l'accroissement de la menace le justifie ;
- demande d'augmenter l'aide technique, financière et matérielle aux Etats qui en ont besoin pour assurer une application universelle de ces dispositions ;
- prie instamment les Etats d'accélérer les études et les recherches relatives à la détection des explosifs et au matériel de sûreté, et de participer activement à l'élaboration d'un régime international de marquage des explosifs en vue de leur détectabilité.

La commission d'enquête recommande que cette résolution de l'assemblée générale de l'O.A.C.I. soit très activement et très fermement mise en œuvre par tous les Etats.

Elle constate à ce sujet que, dans le cadre défini par l'O.A.C.I., diverses actions qui renforcent le contrôle des passagers et des bagages sur l'aéroport de Brazzaville ont été entreprises par les autorités congolaises de l'aviation civile.

3.2. Les mesures de sûreté prescrites par l'O.A.C.I. ne peuvent pas avoir leur pleine efficacité lorsqu'une aérogare a une capacité inadaptée au nombre de ses usagers en raison de ses dimensions trop petites et de son agencement interne :

La commission d'enquête recommande que les impératifs et les objectifs de sûreté soient pris en considération et déclarés *hautement prioritaires lors de la conception initiale ou du* développement d'une aérogare utilisée par des liaisons internationales.

3.3. Dans les conditions actuelles d'exploitation courante, il n'est pas exclu que, lors d'une escale en transit, un passager enregistré pour la destination finale puisse débarquer sans attirer l'attention :

La commission d'enquête recommande que, lors de toute escale en transit, la compagnie effectue systématiquement à l'arrivée le comptage des passagers débarquant, puis, avant le départ, le comptage du total des passagers à bord (passagers en transit plus passagers embarqués).

3.4. L'épave du DC-10 a été localisée dix-sept heures après l'accident :

Considérant qu'il faut mettre en œuvre tous les moyens permettant de réduire le délai de localisation d'un accident ;

Considérant en outre que le système international de localisation par satellite Sarsat-Cospas est opérationnel et permet de connaître avec précision le lieu d'un accident dans un délai de quelques minutes à quatre heures au maximum,

La commission d'enquête :

Recommande que l'emport d'une radio-balise de détresse fonctionnant automatiquement à l'impact soit rendu obligatoire pour les avions de transport public survolant régulièrement des zones inhospitalières ;

Recommande que des exercices de recherches et de sauvetage soient effectués périodiquement entre les centres de régions d'information de vol voisines pour vérifier le bon fonctionnement des moyens de communication et des procédures qui permettent le déclenchement des phases d'urgence.

4. APPROBATION DU RAPPORT

Le présent rapport a été approuvé à l'unanimité par les membres de la commission d'enquête, le 17 septembre 1990.

Les représentants accrédités et les observateurs ont également indiqué leur accord sur ce rapport.

ICAO Ref.: 280/89

5/96, T/P1/2000

Order No. CIR262
Printed in ICAO