

CIAIAC

COMISIÓN DE
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Report A-070/2004

Accident to BOEING B-737,
registration PH-BTC, at
Barcelona Airport (Spain),
on 28 November 2004

(Issue 2)



MINISTERIO
DE FOMENTO

Report

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Foreword

This report is a technical document that reflects the point of view of the Civil Aviation Accident and Incident Investigation Commission (CIAIAC) regarding the circumstances of the accident and its causes and consequences.

In accordance with the provisions of Law 21/2003 and pursuant to Annex 13 of the International Civil Aviation Convention, the investigation is of exclusively a technical nature, and its objective is not the assignment of blame or liability. The investigation was carried out without having necessarily used legal evidence procedures and with no other basic aim than preventing future accidents.

Consequently, any use of this report for purposes other than that of preventing future accidents may lead to erroneous conclusions or interpretations.

This report has originally been issued in Spanish. This English translation is provided for information purposes only.

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Abbreviations

00 °C	Degrees Celsius
ACARS	Aircraft Communications Addressing and Reporting System
AENA	«Aeropuertos Españoles y Navegación Aérea»
AFM	Aircraft Flight Manual, prepared by the manufacturer
AGL	Above Ground Level
AMM	Aircraft Maintenance Manual
AMS	Amsterdam-Schiphol Airport
ATC	Air Traffic Control
ATPL	Airline Transport Pilot License
BCN	Barcelona-El Prat Airport
BEA	«Bureau d'Enquêtes et d'Analyses pour la Sécurité de l'Aviation Civile»
CA	Cabin attendant
CB	Circuit breaker
CECOPS	«Centro de Coordinación de Operaciones», Coordination Centre of Operations
CIAIAC	«Comisión de Investigación de Accidentes e Incidentes de Aviación Civil»
CM1	Captain or pilot in command
CM2	First officer or copilot
CMM	Component Maintenance Manual
CRES	Corrosion resistant steel
CS	Certification Specifications (EASA)
CVR	Cockpit Voice Recorder
deg	Degree(s)
DFDMU	Digital Flight Data Monitoring Unit
DFDR	Digital Flight Data Recorder
DSB	Dutch Safety Board
EASA	European Aviation Safety Agency
EEC	Electronics equipment compartment
ETA	Estimated time of arrival
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FCOM	Flight Crew Operating Manual
FCTM	Flight Crew Training Manual
FDAU	Flight Data Acquisition Unit
FOD	Foreign object debris
ft	Feet
FTD	Fleet Team Digest, maintenance information letter
hh:min:ss	Hours, minutes, seconds
hPa	Hectopascal
HTP	Horizontal tailplane
IAS	Indicated airspeed
ICAO	International Civil Aviation Organization
in	Inch(es)
IPC	Illustrated Parts Catalogue
JAR-OPS	Joint Aviation Requirements-Operations
KLM	Royal Dutch Airlines
kt	Knot(s)
lb	Pound(s)
LH	Left hand
LMLG	Left main landing gear
m	Meter(s)
METAR	Meteorological report
MHz	Megahertz(s)
MLG	Main landing gear
MPD	Maintenance Planning Data
NLG	Nose landing gear
NTSB	National Transportation Safety Board

Abbreviations

NM	Nautical Mile(s)
NWS	Nose wheel steering
OM	Operations Manual, prepared by the operator
P/N	Part Number
PAS	Passenger address system
psi	Pound(s) per square inch
PSU	Passenger Service Unit
RH	Right hand
RMLG	Right main landing gear
rpm	Revolutions per minute
s	Second(s)
S/N	Serial Number
SB	Service Bulletin
SSCVR	Solid state cockpit voice recorder
TAF	Terminal Area Forecast
TSO	Time since overhaul
TWR	ATC Control Tower
USA	United States of America
UTC	Coordinated Universal Time
VAC	Volts alternating current
Vc	Design cruising speed

Synopsis

CIAIAC was notified by phone of the accident on Sunday 28 November 2004 at around 20:05 h local. Investigators of the CIAIAC traveled to the place of the accident on the same day, inspected the wreckage and recovered the flight recorders. The Dutch Safety Board (DSB) was notified and participated in the investigation as State of Registration and of Operation of the aircraft. The National Transportation Safety Board (NTSB) of the U.S.A. also participated in the investigation as State of Design and of Manufacture of the aircraft. Technical support was also obtained from KLM and Boeing. The BEA of France provided support for the downloading and decoding of the information of the flight recorders.

During the takeoff of a scheduled passenger transportation flight from Amsterdam to Barcelona, the aircraft suffered a bird strike in the area of the nose landing gear during rotation. The flight crew informed the ATC and the flight continued without any abnormal indication in the cockpit. During the landing roll at Barcelona, when the nose wheels touched down, the aircraft started deviating to the left of runway 25R. The flight crew applied right rudder, brakes and used the nose wheel steering tiller but could not avoid that the aircraft went off the runway through the unprepared terrain located to the left of runway 25R. The aircraft suffered major damage during that run until it eventually came to a stop close to a wide rain drainage canal located at about 107 m from the runway axis.

An emergency evacuation was carried out in which 5 passengers suffered minor injuries. There was no fire.

The investigation determined that the accident probably happened because during the takeoff a bird strike broke one of the cables of the nose wheel steering system of the aircraft, which made that the nose wheels were rotated to the left when they touched down during landing, causing a veering to the left that could not be arrested by full rudder deflection as the aircraft decelerated. The subsequent application of brakes and other actions by the crew could not avoid that the aircraft went outside the runway surface.

The damages to the aircraft were increased by the condition of the runway strip due to the airport construction works.

Contributing to the breaking of the cable was the fact that the cable was severely worn locally. The wear could be traced back to the incorrect application of grease to the cable system during maintenance. Despite the training and experience of the flight crew, they were unable to quickly recognize the possible cause of the deviation of the aircraft and to keep it on the runway.

Several safety measures were proposed by the airline after the accident, and a total of 11 safety recommendations were issued with the first issue of the report approved in July 2005. After the publication of the report, new information was provided to the investigation team by the operator as a result of tests they carried out and issue 2 of the final report was approved by the CIAIAC on 30 May 2007. This issue 2 includes two new safety recommendations.

1. FACTUAL INFORMATION

1.1. History of the flight

1.1.1. *Takeoff from Amsterdam-Schiphol Airport*

On Sunday 28 November 2004, the flight crew had just completed a flight from London-Heathrow (LHR) to Amsterdam-Schiphol (AMS) on a different aircraft. Then they boarded Boeing 737-400 PH-BTC to fly to Barcelona Airport (BCN). There were 140 passengers on board (including a 7 years old unaccompanied minor) in addition to the pilot, the copilot, who was going to be the pilot flying (PF) for the sector, and 4 cabin attendants. Takeoff weight was 58,948 kg, i.e. 3,874 kg below the maximum.

The take-off run was started on runway 18L of AMS and, approximately at 15:46:15 h¹, one second after «rotate» was called out in the cockpit, the aircraft suffered a bird strike on the nose landing gear area. The aircraft had 152 kt of airspeed and between 1° and 3° of pitch up attitude. The crew had also seen the bird flying low across the runway from left to right.

The crew immediately noticed that it was a bird strike as the sound was very noticeable inside the cockpit. The takeoff continued and at 15:46:23 h the landing gear lever was moved upwards. The crew informed the air traffic control (ATC) that they had had a bird strike «upon rotation». The landing gear retracted normally and there were no abnormal indications in the cockpit instruments. The crew did not notice any unusual vibrations or hydraulic problems.

1.1.2. *Cruise to Barcelona*

The en-route phase of the flight was carried out normally. The crew did not notice any abnormality in the behavior of the aircraft. The flight was transferred to Maastricht air traffic control, and then the ATC told the crew at 15:58:57 h that «...they had a check on the runway and the only [*not understood*] found was small pieces they think it was quite a small bird». The crew answered «Yes, it was not quite a large bird but maybe it is still somewhere in our aircraft». At 16:12 h, they sent an ACARS message to their company departments in Amsterdam and in Barcelona stating «UPON ROTATION BIRD STRIKE IN AMS. POINT OF IMPACT PROBABLY THE NOSE GEAR». The estimated time of arrival (ETA) in Barcelona was 17:37 h at that time. Later on, at 17:17 h, another ACARS message was sent by the crew of PH-BTC that included the text «OPERATION NOT AFFECTED (...)».

¹ Time reference in this report is Coordinated Universal Time (UTC) unless otherwise stated. It is necessary to add one hour to obtain the local time.

1.1.3. Approach and landing at Barcelona Airport

The VOR/DME approach to runway 25R at BCN was normal, in good visibility and gentle weather conditions. The copilot was still the PF and the crew decided to land with flaps 30°, autobrakes setting 2 and standard reverse thrust. The landing gear lever was moved to «DOWN» at 17:36:16 h and the gear lowered and locked down normally.

The crew stated that when the PAPI was visually picked up, the autopilot was disengaged (at 17:38:56 h, with 1224 ft of radioheight). ATC communications were normal and landing clearance was received and acknowledged in time. The last wind check provided to the crew was 240° 08 kt (the magnetic heading of runway 25R is 247°). Ten seconds afterwards the wind was 240° 09 kt.

Touchdown on the main landing gear happened around 17:40:50 in the touchdown zone of 25R, with the aircraft centered in the runway, and with a pitch angle of 4°. A maximum vertical acceleration of 1.43 g was recorded at those moments. Airspeed was approximately 140 kt.

The nose of the aircraft was gently lowered while the thrust levers were being moved to reverse. The digital flight data recorder (DFDR) showed that thrust reversers were deployed at 17:40:51 h and the DFDR ground speed data showed that the average deceleration during the landing rollout from 17:40:51 h to 17:41:01 h was 7.4 ft/sec/sec (0.23 g), which is consistent with Autobrake 2 with thrust reverse selected.

As soon the nose wheels were on the ground, the aircraft had a tendency to deviate to the left. The copilot applied right rudder and initially the aircraft remained a few meters to the left of the centerline of the runway but without further deviation. However, it was noticed that more and more right rudder was needed to stop the tendency of the aircraft to drift to the left. The pilot in command also helped to apply right rudder until full deflection of the pedal was achieved around 17:40:56 h. The copilot checked that symmetrical reverse thrust was being used. The DFDR heading data showed that the airplane longitudinal axis remained parallel with, or slightly to the right of parallel with the runway axis until just after 17:40:58 h. The subsequent lateral drift was evidenced by solid dark skid marks left on the runway by first the left and then the right main gear tires.

The aircraft continued its deviation to the left and the copilot stated he checked his instruments to look for clues of possible malfunctions. According to the statements gathered, one of the crew members started braking manually on the right side. The other stated that, when he noticed that the deviation to the left did not stop, he immediately applied differential braking to the right. Just before that, he saw the amber autobrake light already on, indicating that the autobrakes had been deselected by the manual braking action. As the deviation to the left continued, he started applying symmetrical braking and using the tiller. He kept full rudder deflected all the time. This crew

member thought that his symmetrical braking was very short (maybe a second) after his differential brake application.

The copilot turned the nose wheel steering (NWS) right hand tiller to the right and the captain also started to use the tiller of his side to the right, very smoothly at the beginning to avoid possible abrupt reactions of the aircraft. However, this action had no effect even when full right tiller was achieved.

According to the DFDR, at around 17:41:00 h the thrust reversers were commanded to stow, although this action was probably the result of the aircraft leaving the runway and not by a deliberate action by the crew. At 17:41:01 the longitudinal acceleration increased to nearly -0.5 g.

The aircraft exited the left runway edge (located at the side stripe) and then the shoulder of the runway with airspeed between 91 and 85 kt (i.e. with groundspeed of about 82 kt). After the shoulder there was another asphalted area that was under construction and that was some 10 cm below the level of the runway. This step produced a noticeable lateral acceleration of around -0.29 g at around 17:41:01 h and an oscillation in the vertical acceleration just prior to 17:41:02 h. Afterwards, there was a trench, some 20 cm deep, where the asphalted area ended and unprepared terrain was encountered by the aircraft. A maximum vertical acceleration of 1.494 g was recorded at around 17:41:03 h.

The landing gear was still extended and ploughed the loose sand and unprepared area as the aircraft continued its deviation to the left. The gear then impacted an underground concrete pipeline that was buried some 20 cm in the ground. The aircraft finally came to a stop after running approximately another 55 m. The NLG collapsed rearwards and the LH MLG leg detached from the aircraft. The RH MLG remained in place. The aircraft remained very close to a rain drainage canal some 15 m width and 2.5 m from the edge to the surface of the water. The water depth was approximately 1.5 m.

1.1.4. *Evacuation of the aircraft*

The crew stated that, after the aircraft came to a stop, it became dark in the cockpit and the landing gear horn was sounding. The captain noticed some light smoke almost immediately after coming to a standstill. He described the smell of the smoke as being of an electrical origin. The captain looked at the first officer and saw that he was okay. According to his statement, the smell and sight of the smoke, although minimal, influenced the decision making of the captain to evacuate the aircraft, and he commanded the first officer to start the emergency evacuation procedure. According to his statement, the captain was sure that there was no emergency lighting in the cockpit. When he exited the cockpit the first time, the view of the cabin and for-

ward galley prompted him to go back to check the emergency lights switch, because his feeling was it was also dark in the passenger cabin. Therefore, the captain thought that at least there was a partial failure in the emergency lighting system. In the meantime, at 17:41:16 h and at 17:41:26 h, the air traffic controller called the aircraft asking for an answer. At those moments the aircraft could not be seen from the tower because there was a big cloud of smoke or dust. After the second radio call, the cloud had disappeared somewhat and the aircraft wreckage was seen «crossed and pointing to the tower». The controller told the next approaching aircraft to go around and called the coordinator to start the emergency procedures and to coordinate with Barcelona Area Control Center (ACC).

On board the aircraft, the first officer carried out the memory items of this procedure, but had problems finding the stand-by power switch because it was dark. At 17:41:49 h a short radio transmission, almost unintelligible, was received in the tower that included the word «evacuating». The captain commanded an emergency evacuation through the passenger address system (PAS) and selected the EVAC (evacuation) signal on.

At 17:42:09 h the captain confirmed on the radio they were evacuating the aircraft and called mayday. The fire fighters entered the runway at 17:42:49 h. The captain asked the tower at 17:44:00 h whether emergency vehicles had been sent, and 15 s afterwards he informed that all the passengers had evacuated the aircraft. At 17:44:19 h the fire fighters confirmed by radio that they could see the aircraft wreckage.

The passengers used the doors 1L, 2L and the four overwing exits and the corresponding slides to evacuate the aircraft and moved away from the aircraft towards the runway. Some of the passengers that used door 1L fell into the water of the canal.

As the captain exited the aircraft by the forward entry door 1L slide he felt drops of something. The first officer left the aircraft last and jumped off the slide to the left about three quarters of the way down to avoid landing in the water. He looked back and felt and saw foam coming over the aircraft from the fire brigade. The cabin crew noticed that the fire brigade was active on the right hand side of the aircraft during evacuation. Some stated that they breathed in air containing particles from the fire brigade's foam. According to the fire brigade, the right engine was producing a lot of smoke. They stated that both engines were at high temperature.

1.1.5. *Handling of the passengers after the accident*

After the arrival of all the emergency services, the medical personnel evaluated the possible injuries and it was concluded that there were no serious injuries. Some passengers had minor injuries as a result of the emergency evacuation. Therefore, it was decided to take all the passengers to the terminal, and buses arrived for that purpose. Several airport officials arrived at the accident scene, but there were reports that the

communication of the aircraft crew with some of them was difficult because of the limited command of English the officials had. The emergency plan of the airport required that passengers involved in an accident should be taken to Módulo 0. However, in view of the limited extent of the injuries of the passengers of PH-BTC, it was decided by airport officials that they should be taken to Módulo 4. From there, passengers requiring medical assistance should be taken to the airport medical room. Those were the instructions provided to the airline representative at the airport.

Passengers and crew were therefore taken by bus to Módulo 4 where, according to the statements gathered, there was no organization or clear management to take care of them. There were no blankets or water to be distributed to the passengers, and there was no separate room to be used by them or by the aircraft crew. There were reports that no airport official was in charge of the situation after arrival of the passengers to the terminal.

Passengers who were booked for the now cancelled return flight to AMS came to the same area to pick up their already checked in baggage and became mixed up with the accident passengers. The crew could no longer distinguish between the two groups and were also approached by the passengers of the cancelled flight to AMS.

Later, personnel from other airline located at Barcelona Airport provided help to organize the situation and offered their lounge to the crew and to the passengers that had not yet left. Extensive concern existed among the passengers regarding their hand luggage that was still inside the cabin.

Only five passengers were taken to the medical facilities of the airport, because the other passengers considered they did not need any help. Three of those passengers were taken to hospital for further evaluation but, according to the information gathered, all of them were released the same night and no serious injury was reported.

1.2. Injuries to persons

Injuries	Crew	Passengers	Total in the aircraft	Others
Fatal				
Serious				
Minor		5	5	Not applicable
None	6	135	141	Not applicable
TOTAL	6	140	146	

1.3. Damage to aircraft

The aircraft suffered severe damage in the NLG, which collapsed rearwards and caused damage to the electronics equipment compartment (EEC) door, surrounding fuselage

and avionics racks, LH MLG, which detached, engines and engine nacelles, left wing, and lower part of the fuselage. There was also some damage to interior panels of passenger service units (PSU) and other cabin interior items.

Although there was no obvious extensive damage to the primary structure of the aircraft, it was considered written off.

1.4. Other damage

An unused underground concrete pipe was broken when impacted by the landing gear and several red and white plastic barriers were also broken. There was no other noticeable damage. The runway surface was not affected by hard parts of the aircraft.

1.5. Personnel information

1.5.1. *Pilot in command*

Age/Sex:	47/Male
Nationality:	Dutch
License:	Dutch B1 (Airline Transport Pilot License)
Type rating:	B-737 (300-400-800-900)
Last medical check:	August 2004 (valid for 6 months)
Last proficiency check:	May 2004
Total flight time:	5,414 h
Hours on the type:	5,414 h
Hours in the last 72 h:	10:52 h
Hours in the last 30 days:	54:01 h

The operator stated that his current duty period and previous rest complied with applicable work and rest time regulations.

The pilot in command had also logged 4,226 h flying with the operator as a flight engineer since 1985.

1.5.2. *Copilot*

Age/Sex:	31/Male
Nationality:	Dutch
License:	Dutch B1 (Airline Transport Pilot License)

Type rating:	Boeing 737
Last medical check:	May 2004 (valid for 12 months)
Last proficiency check:	June 2004
Total flight time:	5,117 h
Hours on the type:	1,543 h
Hours in the last 72 h:	10:52 h
Hours in the last 30 days:	48:56 h

The operator stated that his current duty period and previous rest complied with applicable work and rest time regulations.

1.5.3. *Senior cabin attendant or Purser (CA-1)*

Age/Sex:	37/Male
In service with the airline since:	June 1990
In present function since:	January 2001
Last flight safety check:	June 2004
Total flying hours:	8,117 h
Qualified on aircraft types:	Boeing 737, 747
Assigned seat on the accident aircraft:	Front of the aircraft, on the double crew seat facing forward, LH position

1.5.4. *Cabin Attendant 2 (CA-2)*

Age/Sex:	30/Female
In service with the airline:	March 1997
In present function since:	March 1997
Last flight safety check:	April 2004
Total flying hours:	4,580 h
Qualified on aircraft types:	Boeing 737, 747, MD-11
Assigned seat on the accident aircraft:	Front of the aircraft, on the double crew seat facing forward, RH position

1.5.5. Cabin Attendant 3 (CA-3)

Age/Sex: 29/Female
In service with the airline since: April 2004
In present function since: April 2004
Last flight safety check: May 2004
Total flying hours: 1,025 h (had already served a one-year contract with the airline as a CA)
Qualified on aircraft types: Boeing 737, 767, 747
Assigned seat on the accident aircraft: Rear of the aircraft, facing aft, LH position

1.5.6. Cabin Attendant 4 (CA-4)

Age/Sex: 28/Female
In service with the airline since: October 2004
In present function since: October 2004
Last flight safety check: October 2004
Total flying hours: 125 h
Qualified on aircraft types: Boeing 737, 767, 747
Assigned seat on the accident aircraft: Rear of the aircraft, facing aft, RH position

1.6. Aircraft information

1.6.1. Airframe data

Make: Boeing
Model: Boeing 737-406
Serial number: 25424
Registration: PH-BTC
MTOW: 62,822 kg
Operator: KLM Royal Dutch Airlines
Year of delivery: 1992
Total flight time: 31,756 h

Total flight cycles:	22,156 h
Certificate of airworthiness:	n° 4397, valid up to 20 April 2005
Maximum passenger seating capacity:	147

1.6.2. *Aircraft description*

1.6.2.1. Nose wheel steering system

The following information was extracted, almost literally, from the AMM. The NLG is hydraulically actuated to retract forward into the fuselage. The nose gear shock strut is the main supporting member of the nose gear. The shock strut includes an inner and an outer cylinders. There is a fixed centering cam attached to the top of the inner cylinder that mates with a similar cam in the outer cylinder when the inner cylinder extends. As these cams engage, the nose wheels will attain a straight forward position to ensure proper fit in the wheel well on retraction. This also ensures nose wheels to be positioned straight forward when extended for landing.

Nose wheel steering is provided for airplane directional control during ground maneuvers and taxiing. There are two systems to achieve this control:

System A – It supplies hydraulic power that is used to turn the nose from zero to 78 degrees.

System B – It is an alternate nose wheel steering system, an installed option on the PH-BTC, activated by a switch on the captain's forward panel, that allows power from hydraulic system B to turn the nose wheels if power from hydraulic system A is lost.

Steering is controlled:

- by a tiller on the left side wall of the cockpit, and as an installed option on the PH-BTC, by a second tiller on the first officer's side wall.
- and by an interconnect mechanism from the rudder pedals.

The tiller is always overriding the rudder pedal input to the NWS system.

There are internal cams, located in the shock strut, which center the nose gear when the nose gear shock strut is fully extended, therefore turning the wheels or towing should not be attempted unless the shock strut is compressed more than two inches.

Movement of the steering wheel (tiller) in the cockpit is transmitted by cables to a steering metering valve which directs 3,000 psi hydraulic fluid to the nose wheel steering

actuators for turning the steerable portion of the nose gear. A steering wheel movement of 95 degrees will give 78 degrees of nose wheel turning.

Rudder pedal steering is available during takeoff, landing and taxiing, and it is used when small directional changes are required. Full deflection of the rudder pedals produces about 7 degrees of nose wheel steering.

To get both movements there is a nose wheel steering cable system that consists of two sets of 3/32 in diameter cable with tin-coated corrosion-resisting steel terminals (see Figure 1.6.1 from the AMM):

- First set (NWSA and NWSB) is used to actuate the steering metering valve by turning the steering wheel.
- A second set (NGPPA and NGPPB) makes up the squat switch/electric actuator system to engage rudder pedal steering.

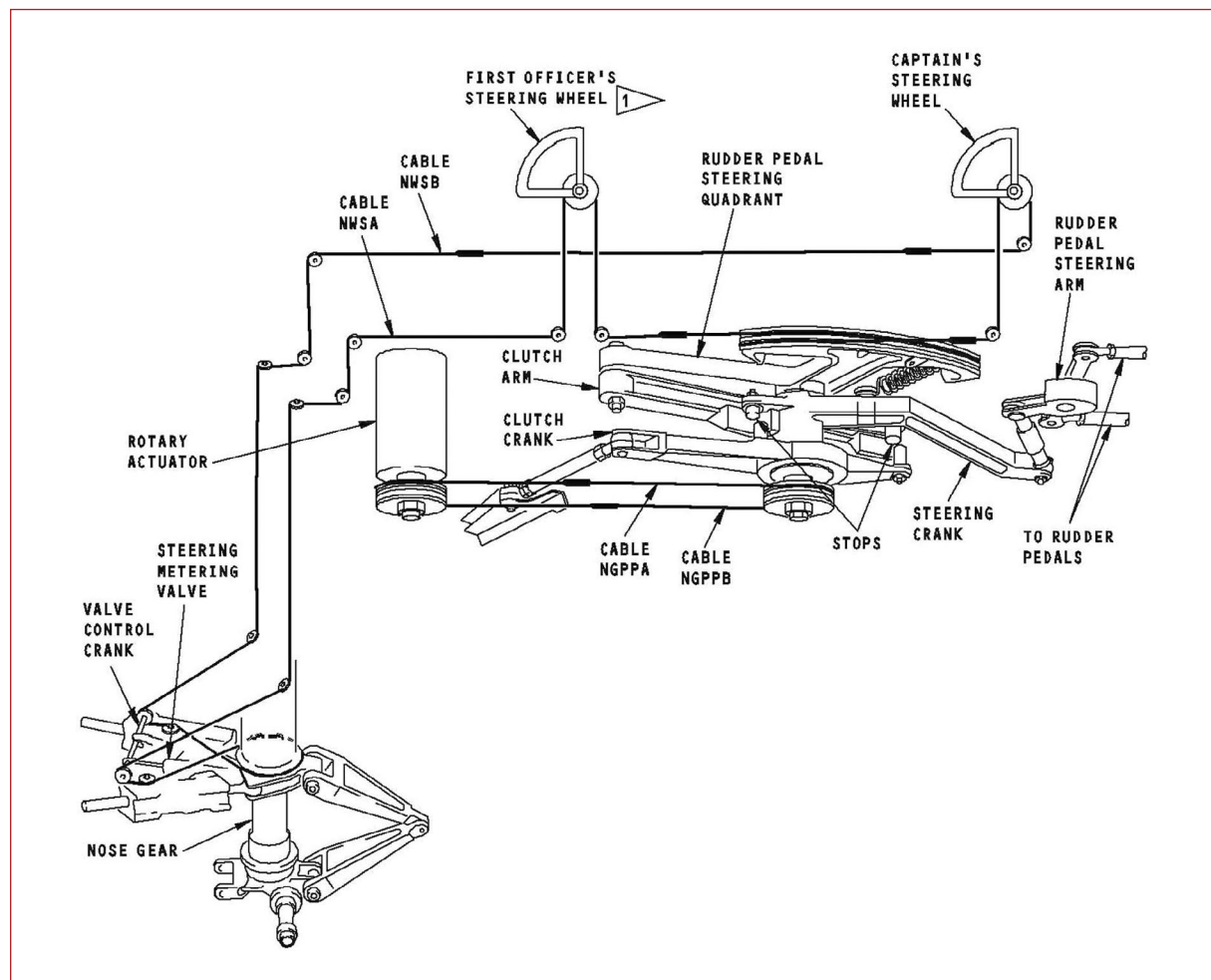


Figure 1.6.1. NWS mechanism from the AMM. Cable NWSB (on the right side of the NLG when looking in the direction of the flight) was found broken after the accident

The cables NWSA and NWSB pass to the pressurized area of the aircraft through holes in a trunnion pressure seal (not shown in the figure).

The steering cables, NWSA and NWSB begin at the steering wheel drum and are fixed in position on the steering collar at the back of the nose gear shock strut, hereby creating an input and feedback loop.

In addition to the internal cams in the shock strut that center the nose gear when the strut is fully extended, the steering system is spring-loaded to the center position.

A cover is installed over the summing mechanism on the front of the steering metering valve. The manufacturer stated that the purpose of the cover is to preclude jamming from tools, loose fasteners, mud, stones, slush and ice, and that the cover was not designed to withstand the impact of birds. (see Figure 1.6.2 with a view of the nose landing gear of PH-BTC after the accident).

The cable had been installed on this aircraft in October 2002, and then inspected in March 2004 without any defect reported. The task to inspect the cables (during 2C maintenance inspections) for broken wires and wear was included in the Maintenance Planning Data (MPD) document. The wording for the task was:

«...inspect the control cables for broken wires and wear in the NLG wheel well. Check associated pulleys and brackets for condition and security of installation. The following cables are located within the nose landing gear wheel well:

- A. NLG manual extension cables (AMM 32-35-21)
- B. NLG steering cables (AMM 32-51-00)

Note: the control cable system must be displaced full travel in each direction for complete inspection at seals, pulleys, and fairlead areas...»

These cables are replaced on-condition based on the inspection results.

There had been a service history of wear observed on the stainless steel cables. This was traced to be due to the rubbing of the cable against sand particles that had been trapped by lubricating grease produced as the cable passed in and out the pressurized zone through the trunnion pressure seal. Therefore, the Fleet Team Digest 737-FTD-32-03008 (last revised on 24 September 2004) issued by the manufacturer stated that grease should not be put in that area. The AMM also contained a statement «Do not grease stainless steel (CRES) cables, it may be only cleaned with a clean rag...».

1.6.2.2. Operational procedures and training

The aircraft operating manual of the operator contained the following instructions for regaining directional control during landing rollout on a slippery runway with a crosswind:

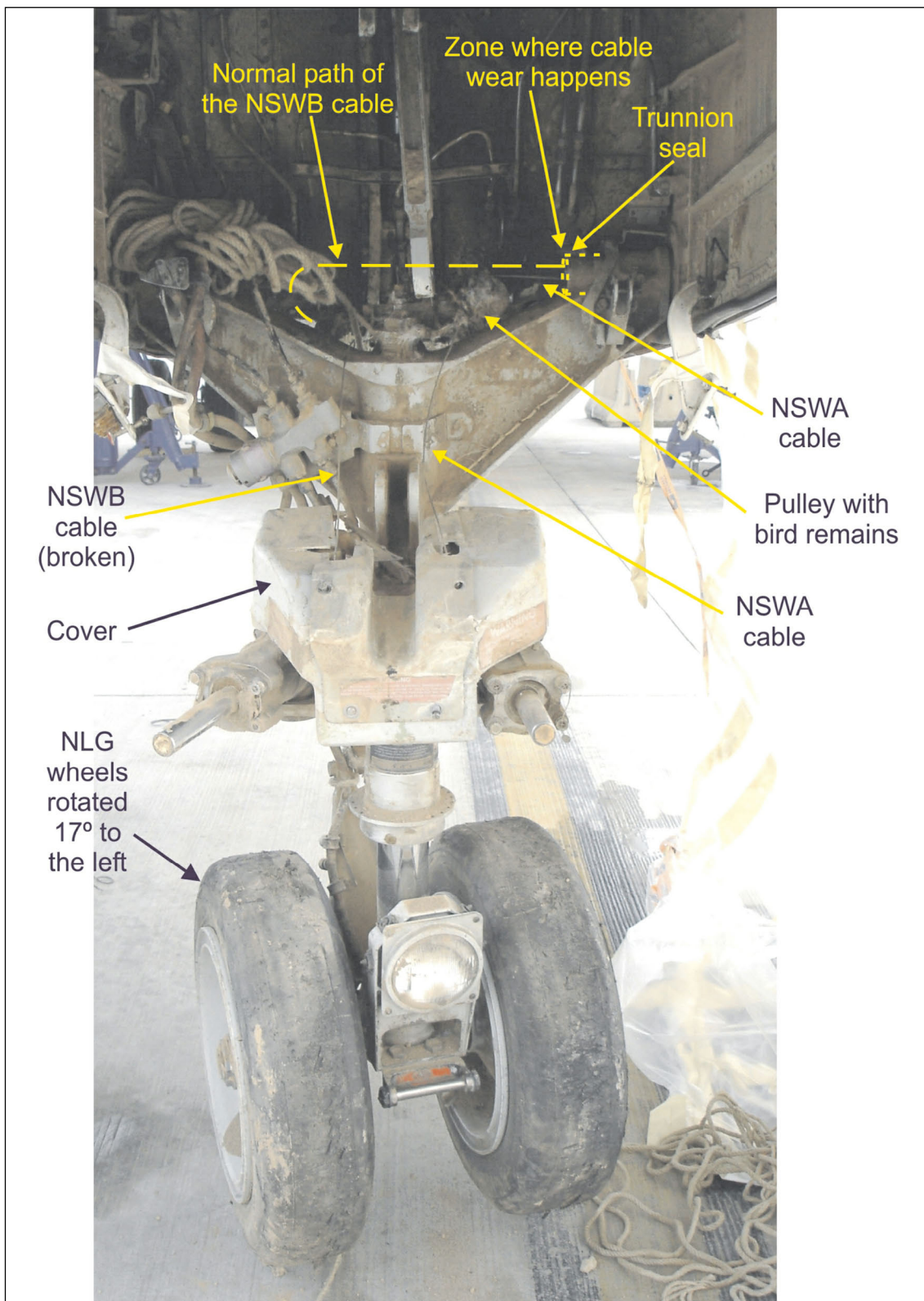


Figure 1.6.2. View of the front part of the NLG after aircraft recovery. The NSWB cable was found broken. The NSWA cable did not break, although it was also worn in the zone of the trunnion seal and its pulley had bird remains

- Anticipation of the effect of any crosswind upon touch down is essential. If the aircraft is allowed to weathervane into wind while reverse thrust is being applied, the reverse thrust component adds to the crosswind force component and aids in drifting the aircraft off the runway.
- If the aircraft track deviates from the runway centreline:
 - Release the (auto) brakes.
 - Select idle reverse thrust. Differential application of reverse thrust must not be used in an attempt to regain directional control. It may even be necessary to apply idle forward thrust temporarily.
 - Regain runway centreline, using positive rudder, rudder pedal steering and differential braking.
- If the aircraft is under control again, resume braking and reverse thrust as required.

However, this procedure would not be applicable to the scenario of the accident, because it happened in gentle weather conditions.

The Boeing 737 series Flight Crew Training Manual (FCTM) stated:

«If the nose wheel is not promptly lowered to the runway, braking and steering capability are significantly degraded and no drag benefit is gained. Rudder control is effective to approximately 60 knots. Rudder pedal steering is sufficient for maintaining directional control during the rollout. Do not use the nose wheel steering wheel until reaching taxi speed. [...] Perform the landing roll procedure immediately after touchdown. Any delay markedly increases the stopping distance.»

The FCTM also contained the following guidance for «Situations beyond the Scope of Non-Normal Checklists»: «Unusual events adversely affecting airplane handling characteristics while airborne may continue to adversely effect airplane characteristics during landing ground roll. Aggressive differential braking and/or use of asymmetrical reverse thrust, in addition to other control inputs, may be required to maintain directional control».

The manufacturer considered that those would be the general instructions that can be provided to crews to accommodate demanding situations that require the use of various controls to prevent drift and runway excursions. This would include, but not limited to blown tires, collapsed main landing gear, strong crosswinds on dry runways, thrust reverser anomalies, icy patches on runways, seized brakes, nose wheel steering anomalies including jammed steering metering valves, etc.

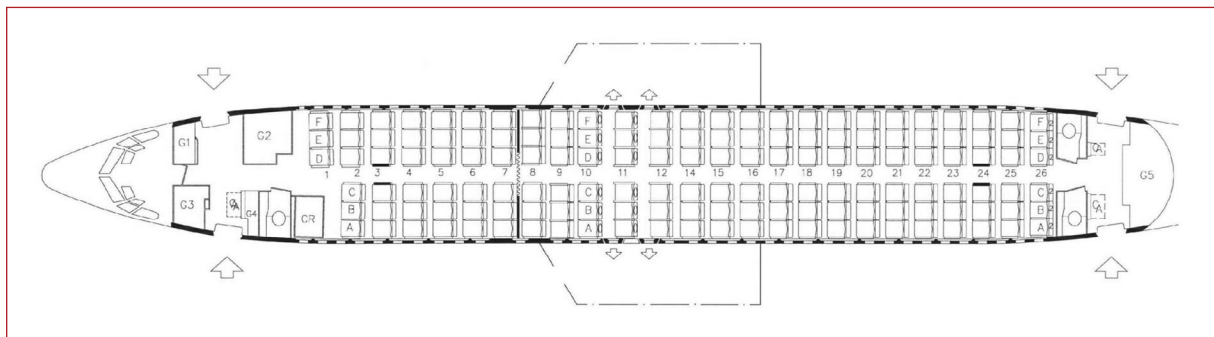
It was understood during the investigation process that no exact data was provided to the crews or even existed regarding the controllability of a Boeing 737 aircraft in the event of a NWS malfunction similar to the one faced during the accident.

The manufacturer informed that in the event of different pedal inputs by the crew members, the greater of the command of the captain or first officer on each right or left pedal would be applied to the brakes of that MLG. The net effect of full differential brake to the right by a crew member and full symmetrical braking by the other would be full brake to the left and to the right main landing gears.

1.6.2.3. Emergency exits

The aircraft has 4 overwing emergency exit hatches, and slides mounted on every door of the airplane. Doors are numbered 1L (forward left), O1L (overwing forward left), O2L (overwing rear left), 2L (rear left) and similarly for 1R, O1R, O2R and 2R.

For egress, the flight crew can use the emergency escape ropes via the two sliding windows of the cockpit.



A malfunction had been identified with deployment of the escape slide of the forward service door (1R). This was the subject of an informative letter («fleet team digest») issued by the manufacturer in December 2002. In some cases the slide became twisted (approximately 90 degrees) during deployment and subsequent inflation. This twisted slide condition rendered the slide and exit unusable for egress. The problem was traced to be probably caused by the escape slide being delayed inside the slide compartment. The manufacturer of the aircraft and the vendor were working on a solution at the time of the PH-BTC accident.

The aircraft had been delivered by the manufacturer with a double seat in front of the overwing exits. Later on, several three-seat sets were installed on those areas. The manufacturer of the aircraft had criteria for the design and installation of seats that included the requirement that «the seat back table latch shall prevent the table from inadvertently deploying following an impact on the seat back table or from brushing during egress/evacuation» (photo 1.15.1.1 refers).

On board the aircraft, on every seat, there was a company «Safety on board» card addressed to the passengers. Several instructions were provided in English language and through drawings regarding the use of the seat belt, oxygen, life vest, opening of the doors, brace position for impact, etc. There was no instruction regarding the need to leave personal baggage behind in the event of an emergency evacuation.

1.7. Meteorological information

The METAR of Barcelona Airport on 28-11-2004 at 18:00 h was:

- Wind: 230°/07 kt.
- Visibility: 8,000 m.
- Few at 1,000 ft.
- Temperature: 13 °C.
- No significant changes expected.

The Terminal Area Forecast (TAF) valid between 16:00 h of 28-11-2004 and 1:00 h of 29-11-2004 was:

- Wind: 250°/12 kt.
- Visibility: Above 10 km.
- Few clouds at 2,500 ft.

The last wind check provided to the crew by the ATC was 240° 08 kt.

1.8. Aids to navigation

Not relevant for this accident. The approach and touchdown were normal.

1.9. Communications

Communications between the aircraft and the ATC control were held without any technical problem except that the first communication from the aircraft to the tower after the accident (at 17:42:08 h) could not be understood because it was coincident with the conversation of the ATC with other aircraft.

A summary of the relevant ATC communications (not literal) is included below.

DFDR UTC Time	ATC COMM (118.1) content or summary of the content of the communication	Comment
	[Synchro ATC-DFDR: ATC 19 sec delayed]	
17:40:02	KLM-1673: «Cleared to land 25R KLM-1673»	Aircraft at 489 ft of radioheight
17:40:50		Touchdown
17:41:16	TWR: «KLM-1673?»	
17:41:26	TWR: «KLM-1673?»	

DFDR UTC Time	ATC COMM (118.1) content or summary of the content of the communication	Comment
17:41:49	TWR: «EXS 313 please go around set heading 328» [KLM transmission, almost unintelligible, possibly «evacuating... KLM 1673 evacuating» not fully understood]	
17:42:05	KLM-1673: «Tower do you read?»	
17:42:08	TWR: «KLM-1673?»	
17:42:09	KLM-1673: «Yea do you read? We are evacuating the aircraft, mayday, mayday, mayday»	
17:42:15	KLM-1673: «Do you read?» [Tower: «I read you»]	
17:42:49	Firefighters on ground frequency (121.7): They are entering the runway	
17:44:00	KLM-1673: «Barcelona tower are you sending emergency vehicles?»	
17:44:06	Firefighters on ground frequency (121.7): They could not see anything there	
17:44:07	TWR: «KLM-1673 Yes sir i will contact with all the staff»	
17:44:15	KLM-1673: «All the passengers are evacuated, the crew is also evacuating now»	
17:44:19	Firefighters on ground frequency (121.7): They have already seen the aircraft wreckage	
17:44:21	[No more communications to or from KLM-1673]	

1.10. Aerodrome information

1.10.1. *Barcelona Airport*

1.10.1.1. General

Barcelona Airport is a major international airport with two parallel runways, 25R-07L (where the accident of PH-BTC happened) and 25L-07R, and another runway 02-20 that crosses the first one. Due to the runway arrangement, it takes a long taxi process to reach the terminal building from the newest runway 25L-07R.

There were construction works being carried out on the left side of runway 25R on the days previous to the accident. Asphalt was being added to some parts of the runway strip. Notice of the works had been provided through several NOTAMS in the preceding months. Because of the works, ILS of runway 25R was out of service.

Annex 14 of ICAO Third Edition, July 1999, paragraph 3.3, required that «A strip including a precision approach runway shall, wherever practicable, extend laterally to a dis-

tance of at least: 150 m where the code number is 3 or 4; [...]» in which no fixed obstacle (other than visual aids) should be placed in at least 60 m on each side of the runway centerline for a code number 4 airport.

There was also a recommendation on Annex 14 that the transverse slopes on that portion of a strip to be graded (75 m on each side for a code number 4 airport) should be adequate to prevent the accumulation of water on the surface but should not exceed: 2.5 per cent where the code number is 3 or 4 [...].

Another recommendation stated that «The transverse slopes of any portion of a strip beyond that to be graded should not exceed an upward slope of 5 per cent as measured in the direction away from the runway».

The strip also had recommendations regarding its strength, in the sense that «within a distance of at least: 75 m where the code number is 4 from the centre line of the runway and its extended centre line should be so prepared or constructed as to minimize hazards arising from differences in load bearing capacity to airplanes which the runway is intended to serve in the event of an airplane running off the runway».

According to the Aeronautical Information Publication (AIP) of Spain, dated 30 September 2004, Runway 25R of Barcelona Airport had 247° magnetic heading and its dimensions were 3,552 × 45 m. It was made of asphaltic concrete with pavement classification number (PCN) 86/F/A/W/T. The strip was 3,672 m long and 120 m width. Therefore, it extended 60 m towards each side of the runway axis.

There was a wide rain drainage canal at around 107 m from the runway axis running in parallel with part of the runway length. Therefore, the canal was outside the declared strip.

The airport informed that the results of the runway friction tests carried out on 9 December 2004 were satisfactory, with the following values of Mu (friction coefficient) obtained:

Third of the runway 07L	Actual Mu value (09-12-04); test speed 96 km/h	Annex 14 design objective for new surface (maximum for all testers)	Annex 14 maintenance planning level (maximum for all testers)	Annex 14 minimum friction level (maximum for all testers)
A	0.72	0.74	0.54	0.42
B	0.73	0.74	0.54	0.42
C	0.83	0.74	0.54	0.42
Total average	0.76	0.74	0.54	0.42

Another friction coefficient measurement test had been carried out on 22-10-2004, using a Mu-meter trailer at 65 km/h starting from 07L threshold. The results were as follows:

Third of the runway 07L	Actual Mu value at 3 m of lateral distance from the runway axis	Actual Mu value at 6 m of lateral distance from the runway axis	Actual Mu value at 10 m of lateral distance from the runway axis	Actual Mu value at 18 m of lateral distance from the runway axis
A	0.68	0.69	0.71	0.79
B	0.66	0.66	0.76	0.79
C	0.67	0.66	0.75	0.81

The reference values of Annex 14 for that test equipment and speed were 0.72 as a design objective for new surface, 0.52 for maintenance planning level and 0.42 for the minimum friction level.

The Attachment A «Guidance Material», supplementary to Annex 14, Volume I, indicated that «In the case of construction, such as runways or taxiways, where the surface must also be flush with the strip surface, a vertical face can be eliminated by chamfering from the top of the construction to not less than 30 cm below the strip surface level. Other objects, the functions of which do not require them to be at surface level, should be buried to a depth of not less than 30 cm».

Due to the construction works being carried out, there were two steps beyond the left shoulder of runway 25R that were not flushed with the surrounding terrain. Those steps induced high accelerations to the aircraft during the accident sequence (see paragraph 1.12 below).

Additionally, there was a concrete pipeline buried around 20 cm under the loose sand against which both the NLG and LMLG impacted (see paragraph 1.12 below).

1.10.1.2. Fire service

The fire category of the airport was 8 (overall aircraft length of 49 m up to but not including 61 m, and fuselage width of 7 m).

There was no rescue equipment. There was no capability to remove disabled aircraft.

The fire brigade was distributed in two different buildings.

1.10.1.3. Emergency plan

Barcelona Airport had in place a detailed emergency plan to be applied in the event of an accident.

The Emergency Plan is a collection of coordinated measures, regulations and procedures made so as to reduce to the minimum the effects that may cause an emergency situation in the Airport or other areas defined in this Plan. The main objectives of Emergency Plan are:

- To save human lives.
- The protection of properties.
- To sustain the operation of aircraft and airport installations.

There are different departments that are involved to achieve these objectives when the accident happens inside the airport premises:

- Control Tower.
- Fire Brigade.
- Medical Services.
- Security Services (Civil Guard, National Police, Airport Security).
- Call Center Service.
- Airlines.
- Handling Companies.
- Other companies that operate at the airport.

The main detection centre of emergencies and alarms is the Control Tower. If an alarm is detected, Control Tower activates the alarm simultaneously at:

- Fire Brigade.
- Sanitary Services.
- CECOPS (Coordination Centre of Operations).

The Airport Authority assumes the command and coordinates the activities of all services involved during the emergency through CECOPS.

CECOPS is the Main Command Post where the first decisions are taken. This responsibility is assumed by Airport Director, Officer on duty or the person to whom the Airport Director delegates this mission.

From the moment the alarm is activated an exchange of calls starts in CECOPS, warning all departments of the airport. The first call is addressed to the Officer on duty, who immediately goes to the place of the accident.

The Officer on duty becomes the Advance Commander who is responsible for coordination of activities in the Operation Area.

The Meeting Point is the place where services wait until their intervention is requested by the Advance Commander; in this case, these services move from Meeting Point to

Operation Area. From the Main Commander Post starts the phase of preparation of the rooms. There are different rooms to be prepared:

- Uninjured people room [placed in the Airport Zone, ground floor Módulo 0, near the Airport Management Building («Bloque Técnico»)].
- Relatives room (placed close to RENFE train station).
- Press room (placed in the Airport Room, first floor of the Airport Management Building).
- Morgue (placed in the Airport Zone, in the Fire Brigade Unit).

Agents of the terminal are the staff in charge of evacuation of the area (if necessary) and to prepare the rooms to receive all the people involved.

Non injured passengers are transferred, by different services (Medical Services, Handling...), to the uninjured people room. There, airline staff is waiting for them in order to provide the victims with all attention they may require (medical and other). In the Relatives Room, family and friends of the victims are attended by psychologists, if needed, and airport staff that try to get details of the passengers of the plane.

The Press Room is the place established to provide the available information to the media.

According to the information provided, the last training drill provided to the airport carried out a training simulation of an aeronautical emergency on 7 June 2003.

1.10.2. *Bird control at Amsterdam Airport*

The Bird Strike Committee of Amsterdam Airport informed that the airport had in place a «Flora and Fauna policy plan for the years 2003-2007». This plan aimed to enlarge flight safety, with respect to flora and fauna.

The primary measures for preventing bird strikes were as follows;

- Taking agricultural engineering measures, making the airport as unattractive for birds as possible.
- Round the clock (24 hours a day) bird inspections by specially trained people.
- During these bird hazard inspections, birds were being chased actively with all proven methods.
- Hazardous birds could be caught or shot if necessary. Provided the necessary permits have been issued by the local government.
- Closing a runway is one of the measures which could and would be taken when flight safety was in danger. This would be done when all other methods fail to be effective.

To measure the effectiveness of the bird strike policy, the Bird Strike Committee issued yearly a bird strike report in which it stated the results over the last year(s). These reports

go back as far as 1979. The results since then stabilized after years of yearly less numbers of bird strikes. Statistics showed that relatively birds of prey became more involved in birds strikes, although the total numbers of bird strikes did not increase (in a long term perspective, with yearly minor variations).

1.11. Flight recorders

1.11.1. Cockpit voice recorder

The aircraft had a solid state cockpit voice recorder (SSCVR, or CVR) L3-Com FA2100, P/N 2100-1020-00, S/N 147305. It records 2 hours of operation in a solid state memory on 2 tracks. The last 30 minutes are recorded on 4 separate tracks.

The CVR was recovered on the same day of the accident and later on it was replayed by the BEA laboratory in Paris. The sound had an acceptable quality and the relevant conversations and cockpit sounds were identified. The whole flight from Amsterdam was recorded.

It is remarkable that the bird strike during the takeoff in Amsterdam was very noticeable in the SSCVR.

A summary of the relevant information of the SSCVR is included in paragraph 1.11.2.

1.11.2. Flight data recorder

The aircraft was equipped with a digital flight data recorder (DFDR) P/N 980-4100-BXUN, S/N 2452. It records at least 25 h of 130 flight data parameters on eight tracks of a magnetic tape. Power to the flight data recorder is supplied automatically by the AIR/GND relay through the test module when the airplane is in flight. When the airplane is on the ground, power is automatically supplied through the engines oil pressure switches when one of the engines is on. If one engine flames out or shuts down for whatever reason and 115 VAC bus 1 goes out, the corresponding power is automatically taken over by the 115 VAC bus 2. There are transfer relays for this process.

The recorder was recovered on the same day of the accident and later on it was downloaded at the BEA laboratory in Paris.

The relevant data corresponding to more than 4 hours of flight before the accident were read. Later on, it was found that the attempt to read out the whole recording failed. It was determined that the recorder device was faulty (i.e. jammed and worn).

The 4 hours of downloaded raw data were converted into engineering units, but it was noticed that some data dropouts occurred several times during the flight.

The recorder had been installed in the aircraft on 16 May 2003, and it had 4,001 h of time since overhaul (TSO).

The status of the DFDR device was later checked in a bench and it was found that the tape had jammed into the crash enclosure case. The specialists that inspected the DFDR considered that the reason for that jamming could be linked to the life time of the tape-based DFDR. After 3,000-4,000 h of service, the tape starts to degrade by stretching its edges, causing the tape belt to be deformed («coning») on the capstan. According to these specialists, this should not affect the normal recording of the flight data during the aircraft operation.

Other specialists consulted considered that the wear of the tape of recorders of such age normally produces dropout of data recording in different flight phases due both to vibration and to the wear of the media itself.

The maintenance program used by the airline required to replace the DFDR «on condition» (i.e. only when a defect is observed). There was a functional check to be carried out at 1C inspections. This check would normally detect a data dropout anomaly and would require a maintenance action in that case. The maintenance carried out by the operator had not detected any need of disassembly or repair of the DFDR before the accident happened.

1.11.2.1. Takeoff at AMS. Relevant flight parameters

From the DFDR data, it was concluded that the takeoff at AMS was normal. A spike of +0.32 g in lateral acceleration (towards the right of the aircraft) was recorded between 15:46:10 h and 15:46:11 h (lateral acceleration is recorded four times per second), although it was considered that this was a spurious value, because the actual bird strike occurred at 15:46:15 h.

The following table shows the value of some relevant parameters during the takeoff at AMS. The accelerations are recorded 4 times per second (lateral and longitudinal) or 8 times per second (vertical or normal acceleration). The figures shown in the table correspond to the closest value to every exact second.

UTC time (hh:min:ss)	Computed air-speed (kt)	Lateral acceleration (g)	Longitudinal acceleration (g)	Vertical (or normal) acceleration (g)	CVR comment	Air/Ground switch	Pitch attitude (deg)	Radio-height (ft)	Landing gear lever position
15:45:37	45	-0,01	-0,04	1,013	(To ATC) CM-1: «ok 1673 rolling»	Ground'	0	-4	—
15:45:38	45	-0,01	-0,04	1,02		Ground'	0	-4	DOWN'
15:45:39	45	-0,01	-0,03	1,048		Ground'	0	-4	—

UTC time (hh:min:ss)	Computed air-speed (kt)	Lateral acceleration (g)	Longitudinal acceleration (g)	Vertical (or normal) acceleration (g)	CVR comment	Air/Ground switch	Pitch attitude (deg)	Radio-height (ft)	Landing gear lever position
15:45:40	45	-0,02	-0,04	1,036		Ground'	0	-4	DOWN'
15:45:41	45	-0,01	-0,04	1,036		Ground'	0	-4	—
15:45:42	45	-0,01	-0,04	1,009		Ground'	0	-4	DOWN'
15:45:43	45	-0,02	-0,03	1,02		Ground'	0	-4	—
15:45:44	45	-0,01	0,02	1,043		Ground'	0	-4	DOWN'
15:45:45	45	-0,02	0,1	1,032		Ground'	0	-4	—
15:45:46	45	-0,01	0,17	1,029		Ground'	0	-4	DOWN'
15:45:47	45	-0,02	0,16	1,069		Ground'	0	-4	—
15:45:48	45	-0,02	0,17	0,984		Ground'	-90	-4	DOWN'
15:45:49	45	-0,03	0,2	1,087		Ground'	-90	-4	—
15:45:50	45	-0,02	0,21	1,029		Ground'	0	-4	DOWN'
15:45:51	47	-0,02	0,2	1,011		Ground'	0	-4	—
15:45:52	53	-0,02	0,19	1,057		Ground'	0	-4	DOWN'
15:45:53	58	-0,02	0,19	1,009		Ground'	0	-4	—
15:45:54	63	-0,01	0,18	1,103		Ground'	0	-4	DOWN'
15:45:55	67	-0,02	0,18	0,979		Ground'	0	-4	—
15:45:56	72	-0,03	0,19	1,011		Ground'	0	-4	DOWN'
15:45:57	78	-0,03	0,18	0,993	CM1: «eighty»	Ground'	0	-4	—
15:45:58	83	-0,04	0,18	1,094		Ground'	0	-4	DOWN'
15:45:59	87	-0,03	0,17	0,926		Ground'	0	-4	—
15:46:00	91	-0,02	0,17	1,041		Ground'	0	-4	DOWN'
15:46:01	96	-0,01	0,17	1,023		Ground'	0	-4	—
15:46:02	100	0	0,16	0,954		Ground'	0	-4	DOWN'
15:46:03	104	-0,02	0,16	1,043		Ground'	0	-4	—
15:46:04	108	-0,03	0,16	1,004		Ground'	0	-4	DOWN'
15:46:05	112	-0,02	0,15	1,018		Ground'	0	-4	—
15:46:06	116	-0,03	0,16	1,089		Ground'	0	-4	DOWN'
15:46:07	121	-0,04	0,15	1,016		Ground'	0	-4	—
15:46:08	126	-0,02	0,15	1,011		Ground'	0	-4	DOWN'
15:46:09	130	-0,02	0,14	1,071		Ground'	0	-4	—
15:46:10	133	-0,04	0,14	1,004		Ground'	0	-4	DOWN'
15:46:11	137	0	0,13	1,025		Ground'	0	-4	—

UTC time (hh:min:ss)	Computed air-speed (kt)	Lateral acceleration (g)	Longitudinal acceleration (g)	Vertical (or normal) acceleration (g)	CVR comment	Air/Ground switch	Pitch attitude (deg)	Radio-height (ft)	Landing gear lever position
15:46:12	141	0	0,14	1,071	CM1: «vee one»	Ground'	0	-4	DOWN'
15:46:13	145	-0,01	0,13	1,004		Ground'	0	668	—
15:46:14	149	-0,01	0,13	1,092	CM1: «rotate»	Ground'	0	-4	DOWN'
15:46:15	152	-0,01	0,13	1,034	«Thump» (sound)	Ground'	0	-4	—
15:46:16	156	-0,01	0,14	1,036	CM: Expression of surprise	Ground'	1	-4	DOWN'
15:46:17	159	-0,02	0,18	0,995	CM: «yes that was against the wheels»	Ground'	3	-2	—
15:46:18	162	-0,02	0,21	1,016		Ground'	5	0	DOWN'
15:46:19	164	-0,02	0,24	1,089		Ground'	7	0	—
15:46:20	167	-0,01	0,25	1,126	CM-2: «gear up»	Air'	10	4	DOWN'
15:46:21	170	-0,02	0,25	1,112		Air'	11	8	—
15:46:22	173	-0,01	0,25	1,204	CM-1: «gear up»	Air'	12	17	DOWN'
15:46:23	174	-0,01	0,25	1,211		Air'	14	32	—
15:46:24	175	-0,01	0,24	1,186		Air'	15	49	UP'
15:46:25	176	-0,02	0,23	1,124		Air'	16	79	—
15:46:26	177					Air'	16	109	UP'
15:46:27	177					Air'	17	150	—
15:46:28	177					Air'	17	186	UP'
15:46:29	177					Air'	17	234	—
15:46:30	177					Air'	18	273	UP'
15:46:31	176					Air'	18	327	—
15:46:32	176				(To the ATC): CM-1: «KLM 1673 upon the rotation we hit a bird it is on the runway»	Air'	18	371	UP'

At 15:58:57 h Maastrich ATC informed the crew that «...they had a check on the runway and the only [not understood] found was small pieces, they think it was quite a small bird». The crew answered «Yes, it was not quite a large bird but maybe it is still somewhere in our aircraft» and thanked the ATC for the information.

1.11.2.2. Relevant flight parameters. Final approach, touchdown and landing roll at BCN

The following table shows the values of some parameters during the final approach and landing at Barcelona Airport.

DFDR UTC Time	Radio- height (ft)	Pitch (deg)	Air- speed (kt)	Ground- speed (kt)	TLA ENG1 (deg)	TLA ENG2 (deg)	Heading (deg)	N1 ENG1 (%)	N2 ENG2 (%)	Rudder pedal (deg) (positive sense means right pedal pressed)	Some CVR sounds/ comments
17:40:00	514	2	148	132	18	19		61	61		
17:40:01	514	3	149	132	18	19		60	61		
17:40:02	489	3	149	132	18	19		60	61		Aircraft acknowledges landing clearance
17:40:03	470	2	149	132	18	19		61	61		
17:40:04	451	2	149	132	18	19		60	61		
17:40:05	434	3	149	133	18	19		61	61		
17:40:06	434	3	149	133	18	19		61	61		
17:40:07	431	2	149	133	18	19		61	61		
17:40:08	422	2	149	133	18	19		60	61		
17:40:09	412	2	149	133	18	19		60	61		
17:40:10	397	3	150	133	18	19		61	61		
17:40:11	385	3	149	134	18	19		60	61		
17:40:12	366	3	149	134	18	19		60	61		
17:40:13	354	3	149	134	18	19		60	61		
17:40:14	345	3	149	133	18	19		61	61		
17:40:15	335	3	149	133	18	19		60	61		
17:40:16	325	3	149	133	18	19		60	61		
17:40:17	311	2	149	134	18	19		60	61		
17:40:18	302	2	148	134	18	19		60	61		
17:40:19	288	2	148	134	18	19		60	61		
17:40:20	273	3	148	134	18	19		60	61	-0,40	
17:40:21	261	3	148	134	18	19		61	61	-0,39	
17:40:22	250	3	148	134	18	19		61	61	-0,39	
17:40:23	238	3	148	134	18	19		61	61	-0,39	
17:40:24	230	4	148	134	19	20		61	61	-0,40	
17:40:25	225	4	148	134	19	20		61	62	-0,39	
17:40:26	211	3	148	134	19	20		37	62	-0,39	
17:40:27	—	7	—	161	—	21		—	13	0,00	
17:40:28	—	—	—	—	—	—		—	—	0,00	

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DFDR UTC Time	Radio- height (ft)	Pitch (deg)	Air- speed (kt)	Ground- speed (kt)	TLA ENG1 (deg)	TLA ENG2 (deg)	Heading (deg)	N1 ENG1 (%)	N2 ENG2 (%)	Rudder pedal (deg) (positive sense means right pedal pressed)	Some CVR sounds/ comments
17:40:29	—	—	148	—	19	—		61	—	-0,36	
17:40:30	164	3	148	134	19	20		61	62	-0,36	
17:40:31	150	3	147	135	19	20		61	62	-0,36	
17:40:32	140	3	146	135	19	20	248	61	61	-0,36	
17:40:33	128	3	147	135	22	22	248	66	65	-0,37	
17:40:34	117	4	148	135	22	24	248	67	68	-0,36	GPWS: «one hundred»
17:40:35	105	3	145	136	22	23	248	66	66	-0,36	
17:40:36	95	3	146	136	22	23	248	66	66	-0,34	
17:40:37	85	4	146	137	22	23	249	66	66	-0,36	
17:40:38	75	4	148	137	22	23	249	65	66	-0,43	
17:40:39	65	4	148	137	20	23	249	65	66	-0,41	
17:40:40	57	3	148	137	20	21	250	63	64	-0,41	GPWS: «fifty»
17:40:41	48	3	435	138	19	21	250	62	62	-0,37	GPWS: «forty»
17:40:42	39	3	148	138	19	20	250	62	62	-0,33	GPWS: «thirty»
17:40:43	31	4	147	138	19	20	249	61	62	-0,37	
17:40:44	22	4	146	138	18	20	249	61	62	-0,26	GPWS: «twenty»
17:40:45	16	4	146	138	18	20	249	61	62	-0,54	GPWS: «ten»
17:40:46	9	5	145	138	9	17	249	56	61	-1,40	
17:40:47	7	5	144	137	0	3	249	49	52	-0,89	
17:40:48	5	4	142	136	0	0	249	44	46	0,59	
17:40:49	3	5	141	135	-1	0	249	41	42	-0,92	
17:40:50	1	4	140	134	54	56	249	38	39	-1,04	First contact of RH MLG
17:40:51	1	4	137	131	36	54	249	37	37	-0,43	Sound of reverse
17:40:52	1	3	131	127	32	32	248	46	40	0,78	Possible touchdown of NLG
17:40:53	-1	1	126	122	32	31	248	67	58	2,83	
17:40:54	-1	1	120	118	32	31	248	82	77	6,22	
17:40:55	-1	0	116	113	32	31	248	82	88	10,94	Interjection of surprise of the crew
17:40:56	-1	0	111	108	32	31	248	81	87	13,20	
17:40:57	-1	0	107	104	32	31	249	80	87	13,13	

DFDR UTC Time	Radio- height (ft)	Pitch (deg)	Air- speed (kt)	Ground- speed (kt)	TLA ENG1 (deg)	TLA ENG2 (deg)	Heading (deg)	N1 ENG1 (%)	N2 ENG2 (%)	Rudder pedal (deg) (positive sense means right pedal pressed)	Some CVR sounds/ comments
17:40:58	-1	0	102	99	31	31	249	80	87	13,19	
17:40:59	-1	0	99	95	32	31	247	80	87	13,48	
17:41:00	-1	0	95	91	32	31	244	80	87	13,60	
17:41:01	-1	0	91	87	-1	58	239	72	84	13,67	Abrupt noise (aircraft leaving the runway)
17:41:02	-1	-1	85	81	-1	-2	235	59	74	13,65	
17:41:03	-1	-1	81	74	-1	-2	230	51	63	13,43	
17:41:04	-1	0	—	71	—	-2	—	—	24	0,00	
17:41:05	—	—	70	—	-1	—	226	116	—	11,01	
17:41:06	18	-56	—	47	—	-45	27	—	—		End of CVR recording (established at 17:41:06,000)

Figure 1.11.2.1 shows the value of some relevant flight parameters during the landing roll on runway 25R of Barcelona Airport. Figure 1.11.2.2 gives the values of the accelerations during that phase. In both cases the data are presented as obtained, without any filtering work to eliminate the possible spurious values.

The touchdown was carried out on the main landing gear with around 140 kt and 1.4 g of vertical (or normal) acceleration at 17:40:50 h. Thrust levers were moved towards reverse almost immediately after touchdown. The aircraft decelerated normally and the nose wheel was gently lowered. When the pitch angle was between 3° and 1° nose up (and the NLG just touched the ground), right rudder pedal started to be applied.

The deflection of the pedal continued until it reached the maximum with airspeed of 111 kt at 17:40:56 h.

Between 17:41:01 and 17:41:03 h the aircraft exited the paved surface of the runway and noises were recorded on the CVR. At around 17:41:01 h the left and right thrust reversers were stowed. The DFDR showed that the LH thrust lever was moved to idle, and the value of LH N1 (rotational speed of the fan) also decreased. The RH thrust lever was advanced and then also retarded to idle. The maximum lateral acceleration (-0.29 g) was recorded at 17:41:01 h with 91 kt of airspeed (87 kt of groundspeed) while the maximum vertical acceleration (1.49 g) was recorded at 17:41:03 h with 81 kt of airspeed (74 kt of groundspeed).

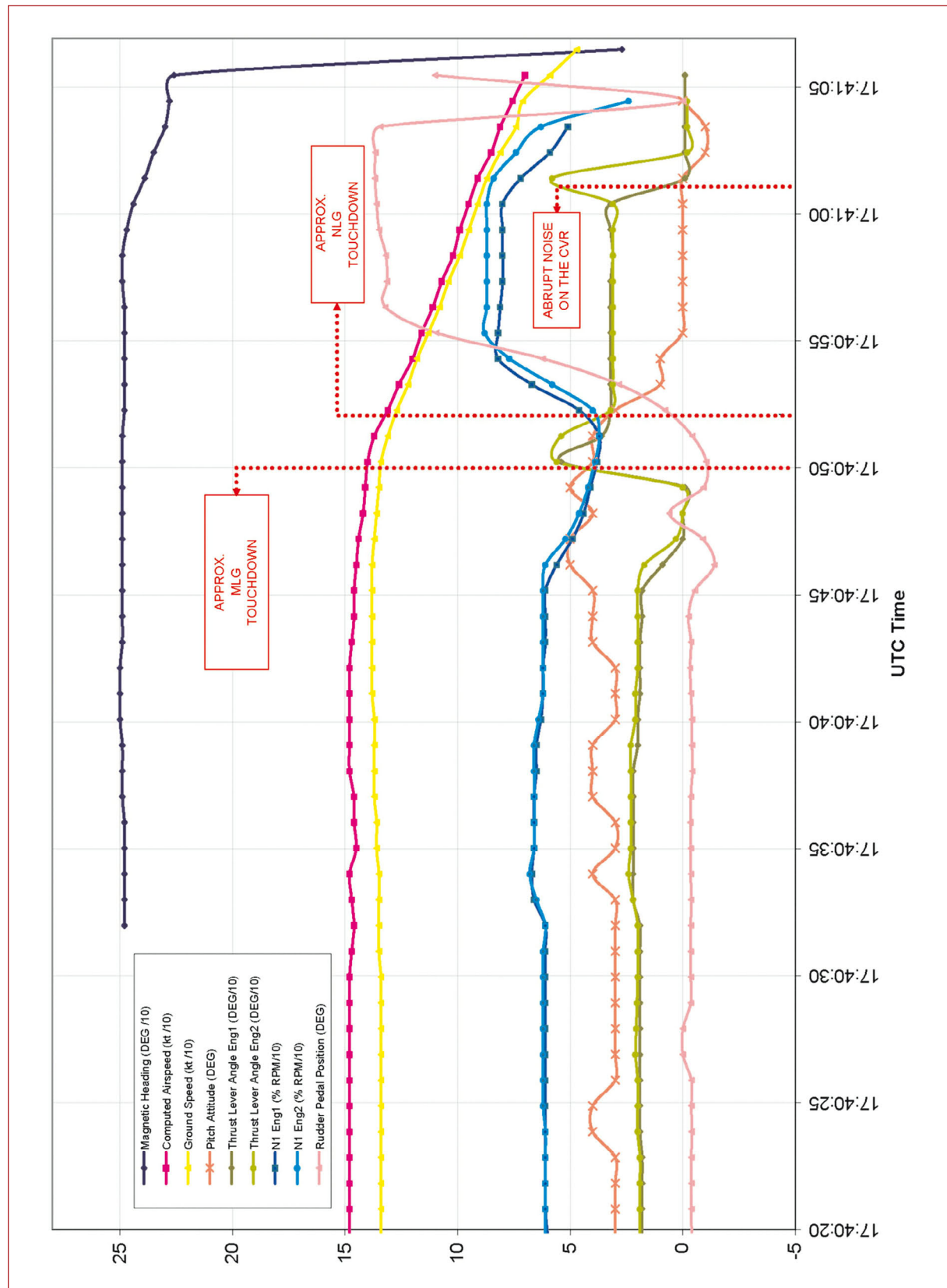


Figure 1.11.2.1. Several parameters during landing

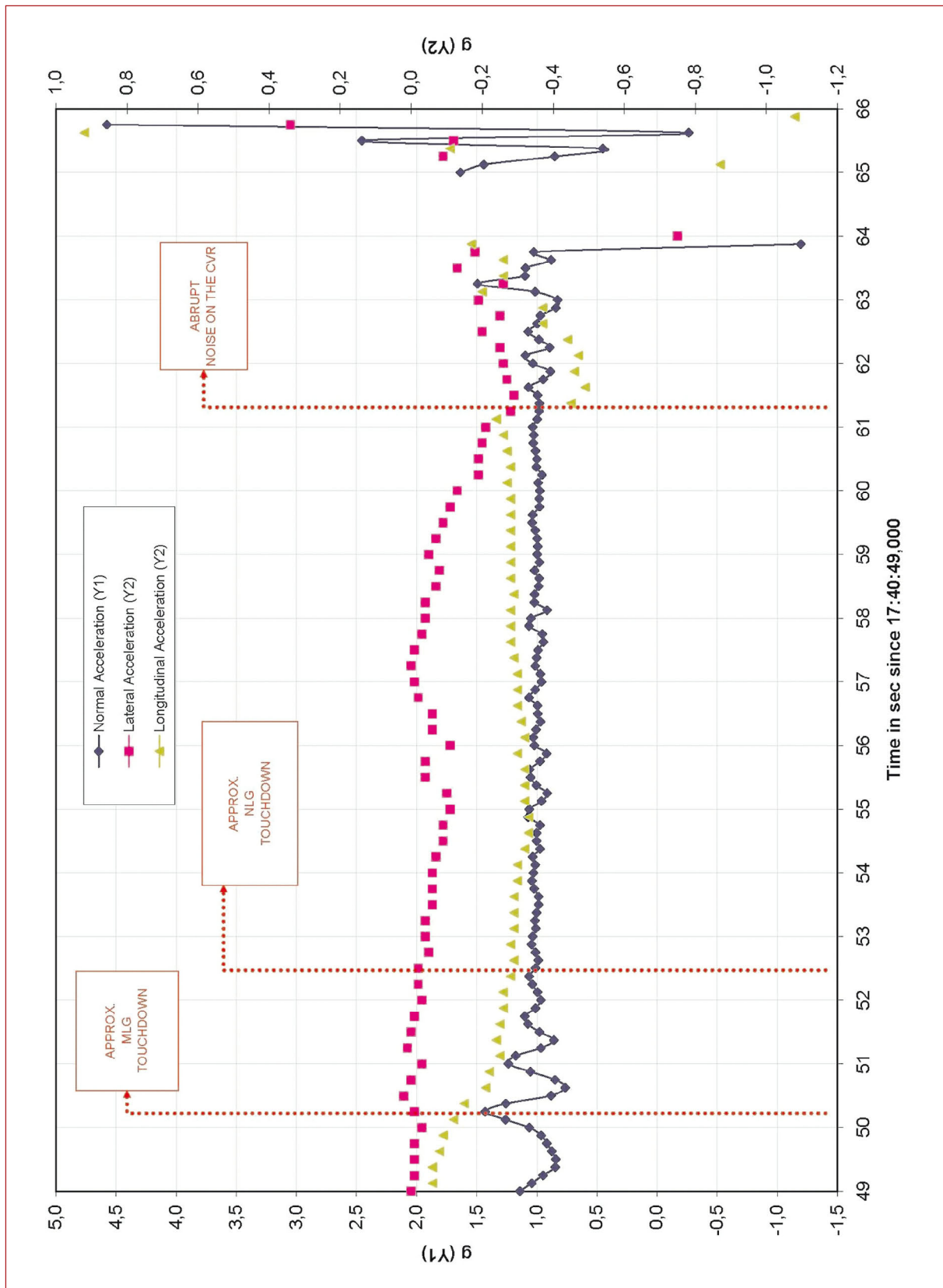


Figure 1.11.2.2. Accelerations during touchdown and landing roll

Since that moment (17:41:03 h), the parameters recorded on the DFDR are no longer reliable, according to the conclusion of the manufacturer specialists. The aircraft suffered heavy deceleration in the unprepared area beside the runway until it came to a stop. Therefore, it was not possible to ascertain the position of the levers or the values of the accelerations during the final part of the off-runway run.

1.11.3. Quick access recorder (QAR)

The aircraft was also equipped with a quick access recorder that recorded several flight parameters (including those recorded by the DFDR) on a removable tape cartridge. Those parameters included several related to electrical and hydraulic systems that were relevant in this accident as regards to brake system status and individual pressures and stop of the electrical power to the flight recorders. Unlike the DFDR, the QAR is not designed to survive an accident. It is used for maintenance and operational purposes.

The cartridge or disk was downloaded by the airline but the recorded data ended when the aircraft was in final approach at 216 ft of radio-altitude, heading 249° and an air-speed of 148 kt.

The disk was then handed over to the manufacturer to make another attempt to download the important data of the landing roll phase. However, the data could not be downloaded either. Since the aircraft had a Digital Flight Data Monitoring Unit (DFDMU) Teledyne P/N 227000-335, S/N 318, with an integral QAR installed, it was decided to check whether some data remained in the non-volatile memory of that unit. For that purpose, the original optical disk was used to download the buffer of the DFDMU, but no useful data could be obtained.

The reason for the discontinuity of data is that normally, to improve the quality of the recording to the disk with minimal vibration, no writing of data occurs on approach, landing and taxi phases. After the aircraft has been parked for about 5 minutes, the data in the buffer begins to transfer to the disk.

1.12. Wreckage and impact information

1.12.1. Impact area

The aircraft exited the surface of runway 25R and went through another paved area under construction of some 10 m in width after jumping a step of approximately 10 cm of height. After passing over a trench around 20 cm deep, it then entered an unprepared zone covered mostly by sand and the landing gear dragged through the unprepared surface. The aircraft crossed a plastic fence line and suffered some damage from iron bars that were supporting construction signaling nets. The NLG and the LH MLG hit a buried pipeline that probably made them collapse and detach, respectively (see white arrows in the attached Photo 1.12.1.1).



Photo 1.12.1.1. Buried pipe noted in the tracks of the LH MLG and NLG

The aircraft came to a stop close to the edge of a rain drainage canal that ran approximately parallel to runway 25R. The canal was approximately 15 m wide, and 2.5 m high from the surface of the water. The water depth was approximately 1.5 m.

1.12.2. *Runway tracks and marks in the terrain*

See attached drawings in Appendix A.

The exact touchdown point of the aircraft could not be determined by runway marks. There were no noticeable or abnormal marks before the end of the touchdown zone of runway 25R. The airport personnel informed that when they inspected the runway after the accident, no detached part of the aircraft was found on the runway surface.

The beginning of the marks of the two nose wheels were observed over the first runway center line after the last twin marks of the end of the touchdown zone, close to the zone of rapid exit B-A. The marks did not have noticeable groove tracks, and therefore it was determined that both NLG wheels were rotated to the left since the beginning of the marks. The marks started immediately to separate to the left of the runway axis.



Photo 1.12.1.2. Final position of the aircraft close to the edge of the canal

The first marks of the LH MLG (see Appendix A) could be noticed around 253 m afterwards and after another 132 m the first marks of the RH MLG were noted. The marks were continuous and did not show intermittent tire skids and releases. The NLG marks had darkened a lot in this zone.

At the beginning of both MLG marks the grooves of the tire treads could be seen in the marks. The lateral distance between the NLG and the LH MLG was much less than the distance between the NLG and the RH MLG, showing an important lateral component of displacement towards the left.

Around 83 m after the first RH MLG marks appeared they crossed the left side stripe of runway 25R, very close to a runway edge light. The grooves of LH and RH tires could still be noticed.

Around 50 m after the previous point, the marks of the RH MLG left the paved shoulder of runway 25R and entered another paved area still under construction.

The aircraft skidded for 142 m over that paved area and the adjacent zone covered by sand until it came to a stop. The final position of the center point of the wing was approximately 88 m to the left of the runway axis and 1606 m from the 25R threshold line. The left wing tip was also displaced approximately 88 m from the runway center-line, and the fuselage had a heading of 174° (i.e. had an angle of around 73° nose left with respect to the runway axis).

Therefore, the aircraft wreckage was outside the declared runway strip in the AIP for runway 25R-07L (120 m width, i.e. 60 m to each side of the runway axis, see paragraph 1.10.1 above).

1.12.3. *Wreckage layout*

The LH engine nacelle was dragging over the terrain for around 10 m and finally remained buried almost 50 cm in the ground. The engine had ingested parts of the plastic fences and nets used to signal the construction area. Some of those parts still remained in the rear part of the engine.

The LH MLG detached after the forward and the rear fuses broke. Its inboard wheel tire damaged the bottom part of the LH trailing edge flap fairing assembly.

The RH MLG remained in place although it was buried in the soft sand for more than three quarters of the diameter of its wheels

The RH engine appeared without external solid objects inside, although it had remains of fire fighting blue foam. The ground in that area was flooded by foam and mud had

appeared. The ground around other parts of the aircraft did not have mud. It was concluded that the RH engine did not absorb parts of the construction plastic fences or nets.

During the final impacts, the drag link broke and the NLG collapsed rearwards, and it broke some nets and fences of the construction area. The NLG doors were partially detached.

It was estimated that the fuselage had a left roll angle of around 10° and a pitch up angle of around 4°.

There are 5 spoiler panels on every wing. They are numbered from 1 to 10 beginning from the LH wingtip. The following panels appeared up: 1, 3, 9 and 10 (only partially).

1.12.4. *Status of the controls and indicators of the aircraft*

When the cockpit was inspected the day of the accident, the following information relevant to the accident could be obtained:

- No circuit breaker was found tripped.
- Flap lever 40°.
- Horizontal Stabilizer trim: 5 units.
- Left rudder pedal deflected.
- Rudder trim with OFF flag (no power applied).
- A 1/2 litre water bottle on the CM1 pedals.
- A glasses case on the CM2 pedals.
- Speed brake lever all the way down.
- Thrust reversers stowed.
- Landing gear down.
- Tiller CM1 all the way to the right.
- Tiller CM2 centered.
- Windows open.
- Emergency escape ropes not released (i.e. still stowed).
- Engine and APU fire warning switches were pulled and rotated.
- Autobrake 2 selected.
- Light of «APU bottle discharged» lit (it was the only light ON in the whole cockpit).

1.13. Medical and pathological information

There were five people that suffered minor injuries, like bruises and contusions that were a consequence of the emergency evacuation. They were first attended on site by the medical services of the airport. When the passengers were taken to the terminal,

some of the injured people were offered to be sent to the medical service facilities for a better attention, but they rejected this possibility. Later on, a total of 5 passengers were taken by bus to those facilities, and three of them were sent to hospital for further evaluation. They were all released within 48 h.

1.14. Fire

There was no fire. After the alarm sounded, two vehicles of the North fire brigade moved immediately towards the aircraft wreckage. It was dark and it took some time to locate the aircraft. Other vehicles also went to the accident site shortly afterwards. The fire brigade stated in their report that a big cloud of dust could be seen on the runway. When they located the aircraft, a large number of occupants were already outside the aircraft. They saw smoke coming out the RH engine and therefore quickly applied water and fire extinguisher agent to the nacelle. After the evacuation, the fire fighters also entered the aircraft with a hose to ensure that no person remained inside.

1.15. Survival aspects

1.15.1. Cabin damage

The passenger cabin did not suffer serious damage or deformations. All the seats (there are 6 seats abreast named from left to right ABCDEF and separated by a single aisle) remained undamaged and attached to their seat tracks.

The meal tables in front of the following seats were found down (i.e. in meal serving position): 4D, 8B, 10A, 10D, 10E, 11B (forward LH over wing emergency exit path) and 21D.

The meal tray table of the back of seat 10B (in front of seat 11B), which was located in the forward left hand emergency exit passageway, was found to have the restrain pin on its right hand side (i.e. towards the aisle). Therefore, the normal escape path of the passengers towards the type III emergency exit could easily release the tray (see Photo 1.15.1.1, white arrow in central seat back).

The following passenger service units (PSU) (referenced to the corresponding row number) were found to have fallen (i.e. they were hanging down vertically):

State	Row numbers on the left side	Row numbers on the right side
	3, 5, 10, 16, 18, 20, 22	25



Figure 1.15.1.1. The latch of the meal table of the centre seat may rotate towards the sense of the Type III emergency exit escape path (to the left of the photo) and therefore it could be released during the emergency evacuation

The following PSU panels (referenced to the corresponding row number) were found open:

State	Row numbers on the left side	Row numbers on the right side
Totally open (restrained by the lanyard; the latch broke)	15, 16, 17, 18	
Partially open (restrained by the lanyard)	22, 23, 26	26

It was found that a lot of latches of the PSU panels were broken apparently due to lateral inertia loads towards the left of the aircraft or by the bending and torsion of the fuselage (see Photo 1.15.1.2).

When the aircraft was inspected after the accident, the ceiling panels located in the forward and rear flight attendants compartments were in place. However, according to the statements gathered both panels detached after the accident and were put in place again by cabin attendants (see Photo 1.15.1.3). The lanyard of the forward ceiling panel broke, and that of the rear ceiling released without breaking. The hook was not at its normal position (in the middle of the lanyard).

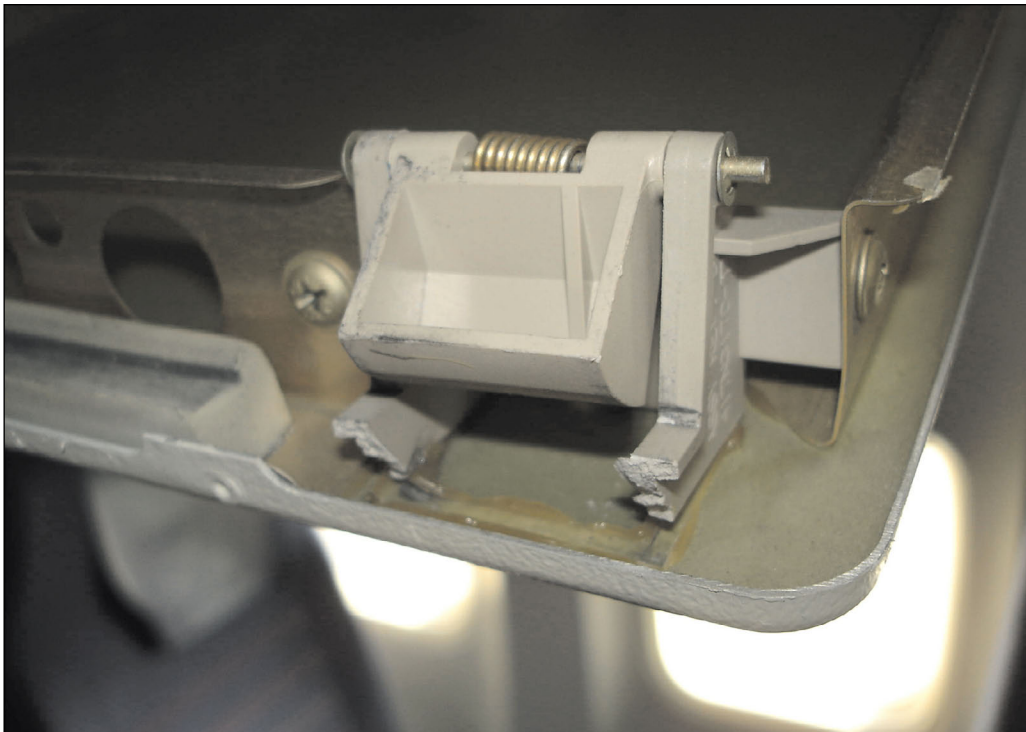


Figure 1.15.1.2. Detail of a PSU panel latch broken on the left side of the aircraft



Figure 1.15.1.3. Ceiling panel in the rear cabin attendant compartment. During the inspection after the accident it was found closed, but witnesses stated that it opened after the aircraft came to a stop, therefore obstructing the path towards emergency exits L2 and R2. The lanyard released. The hook is at the end of the lanyard assembly

1.15.2. Evacuation of the aircraft

After the accident, all the doors and exits of the aircraft (doors 1L, 1R, 2L and 2R and four over wing exits) were found open. The over wing exit hatches were found outside the cabin, beside the wing.

All the escape slides were found inflated, but the 1R slide was found twisted rearwards (i.e. front edge up and rear edge down) in a way that would have prevented its use for evacuation (see Photo 1.15.2).

1.15.2.1. Cabin attendant statements

According to cabin attendant statements gathered, the boarding and pre-flight activities at AMS were normal. The aircraft was almost full and there was a lot of carry-on baggage that was difficult to stow in the cabin. The rest of the flight was normal.

During the landing roll at BCN, after the heavy shaking and bouncing of the aircraft in the last part of its movement before coming to a stop, the ceiling panels of the rear and of the forward cabin fell open. It was dark and no passenger panic was observed. The evacuation signal was activated from the cockpit and a voice command to evacuate was given through the PA.



Figure 1.15.2. Escape slide of door 1R was twisted

The forward entry door (1L) opened normally and the slide inflated normally, although the door did not lock in the open position at this first attempt and another movement was needed to bring it to the fully open and locked position. The forward service door (1R) also opened normally and was taken to the fully open position, although it did not lock in that position and swung back again. The slide inflated normally, although it remained folded approximately half way down. The CA2 informed the senior cabin attendant (CA1) that the exit could not be used. In the rear part of the cabin, the entry door (2L) could be opened and latched at the second attempt. CA3 reported that the door was «extremely heavy» to open, and that it started closing again while she had locked it against the fuselage. The aft service door (2R) could be opened but the slide appeared to be folded and the door swung back hitting the slide. The cabin attendant opening the door concluded that this exit was unusable and both rear cabin attendants directed passengers towards door 2L.

Several cabin attendants stated that if they had been alone in the galley area (without other colleague cabin attendant in the event of a flight with minimum cabin crew) they could have opened only one door, and if that door cannot be opened under certain situations, it would be very hard to reach the other door if the galley is already jammed by passengers in panic.

They also stated that maybe the message «leave luggage» could be added to emergency evacuation command.

Some passengers who were standing in the aisle had to be urged to move and evacuate the aircraft. Other passengers were observed opening overhead bins and retrieving their hand luggage. The cabin attendants commanded them to leave any luggage and to quickly evacuate the aircraft. No cabin attendant stated seeing any emergency lighting on at those moments.

All the four overwing emergency exits were opened by passengers at those moments.

Some passengers that used exit 1L fell in the water of the canal, since the slide was very close to the edge. On board the aircraft there was a 7 year-old unaccompanied minor that was found on ground later on in the care of a passenger.

The cabin attendants had taken some emergency equipment items as megaphones, torches and the first aid kit.

During evacuation, the fire brigade was seen actuating on the right side of the aircraft.

After the crew and passengers were taken to the arrival terminal area, the situation became very confusing and nobody was able to inform the crew or passengers about the steps to be taken. The crew felt frustration as the accident passengers were mixed with other passengers.

1.15.2.2. Passenger statements

Several weeks after the accident, questionnaires in English, Dutch and Spanish languages were sent by the investigation team to the aircraft passengers through the operator. The questionnaires included detailed questions regarding the sequences of the accident and of the emergency evacuation, including door used, injuries sustained, instructions provided, problems encountered, etc.

By May 2005, a total of 43 passengers out of 140 had answered including reports of witnessing 6 others. Of 3 more passengers data were retrieved through reports made by the Police. They provided useful information. A brief summary of the most important aspects reported is provided below. A most detailed study of the completed questionnaires, prepared with the support of KLM cabin safety specialists, is included in Appendix B.

There were 1 commercial pilot, 1 retired airline captain and 2 ex-stewardesses on board as passengers. There were approximately 64% of males and 36% of females among the passengers.

Seven people that answered the questionnaires reported having suffered minor injuries (small cuts, bruises, hits, etc.) during the event, mostly attributed to the emergency evacuation.

Several Spanish speaking passengers stated that they did not completely understand the pre-flight safety instructions because they were provided in English and Dutch languages.

A passenger restrained his children by hand, because he thought they would be thrown off during the off-runway run even though they had the seat belt fastened. Other passengers reported hitting the backseat in front of them even though they had the seat belt fastened.

Smoke, steam or dust was seen coming out from the ceiling of the cabin. Some passengers stated that the cabin was completely dark after the accident. Other stated that some emergency lighting was observed to be on. Several passengers used the overwing exits on the right side. The passengers that opened overwing exits O1L, O1R and O2R answered the questionnaire. Some problems were faced with door O1L but they used a brusque hit and could finally open it. The other overwing doors were apparently opened very easily. Some passengers stated that specific instructions were given to people sitting next to those doors before the start of the flight. A passenger was seen helping and providing instructions to people outside the left overwing exits because it was found that he had professional aeronautical experience. A passenger recommended using louder messages for the emergency evacuation. Other recommended using several languages for those messages.

From the answers received, 15 passengers used 2L; 15 passengers used 1L; 8 passengers used O1L; 5 passengers used O1R and 3 passengers used O2R. A passenger did not remember exactly which exit he used.

Several passengers acknowledged that they opened the overhead bins and took some personal items with them during the evacuation. The estimations of the passengers about the time required to evacuate the aircraft were between 30 sec and 5 minutes. The most common answer was 2-3 minutes. It was cold outside, and at least two passengers were soaked because they fell in the canal. Some passengers had left their shoes on board.

The comments stated that the arrival of the fire fighters, and especially of the ambulances, was perceived as having taken a long time.

Almost all the retrieved comments included complaints about the after-accident care of the passengers. No organization at all was perceived by the passengers at the terminal, and no information on the steps to be taken was observed. Most passengers were worried about their personal belongings and checked luggage that were on board the aircraft. A long line was formed to take note of the details of the luggage. Communication problems were also faced because of the limited command of English of the few people taking note of the passengers' names. No authority in charge was identified at the building to provide a debriefing or instructions about what to do. No blankets or beverages, or psychological assistance, was available. Most comments coincided in that frustration and chaos were faced by the aircraft occupants at the airport terminal.

1.16. Tests and research

1.16.1. *Visual inspection of the aircraft at the apron*

1.16.1.1. Flight controls

When the aircraft was inspected at the apron, the flaps and spoilers were retracted. The slats were still deployed.

The left wingtip and left aileron appeared without damage. The lower part of the flap fairing n° 1 appeared broken and had traces of hydraulic fluid. It seemed it was hit by the LH wheel of the MLG when it detached.

The left aileron cable broke at the left wing root. There were also two cables of the spoiler system broken.

The left flaps shaft assembly drive detached from its coupling to the flap drive unit.

There were traces of dirt and mud at the bottom of the rear cone and on the lower surface of the horizontal tail plane (HTP).

On the right wing, the aileron and spoilers cables appeared intact. There was no apparent external damage to the right wing and right engine pylon, including the aileron, flaps and slats surfaces.

There was no obvious structural damage (buckling or wrinkling of the skin) to the rear part of the fuselage (behind the wing root).

A tube of the hydraulic system broke on the left side (close to the LH MLG well. Another tube with hydraulic power to the spoilers system broke in the area of the LH MLG forward fuse.

A hose of the brake system broke on the LH MLG.

1.16.1.2. Landing gear

1.16.1.2.1. *Nose landing gear*

The shock strut of the NLG was folded backwards into lower aft wheel well bulkhead. A lot of scratches and dents were observed in the area. The shock strut was still attached to the sidewall trunnion fittings. The trunnion pins and bearings were intact. The shock strut trunnion area still had bird remains on it. The shock strut appeared to be charged with fluid and gas and it did not appear to leak any fluid. All components were contaminated with dirt.

In the nose wheel steering system, the bearings in both upper shock strut pulleys were pushed out such that the pulleys were wedged against the pulley bracket and did not rotate. The NWSB cable was fractured at a point 56 cm from the turnbuckle (see Figure 1.6.2). It appeared to be at the approximate point where it entered into the trunnion pin pressure seal. Examination of the cable under a magnifying glass showed signs of worn cable strands and wires. The upper pulley bracket for NWSB cable was fractured. Both cables and pulleys had bird remains on them. The steering valve cover was smashed in several places and attach brackets were fractured. Several other steering mechanism components were also fractured. The steering valve was intact. All components were heavily contaminated with dirt. First officer's tiller felt normal when operated left or right. Captain's tiller was very stiff in left direction and bound up prior to full turn inputs. Right turns had no resistance at all regardless of turn angle input. Rudder pedal operation felt normal.

The NLG tires were severely scuffed and worn. In several areas, there was no tread left and the fabric was exposed. Outboard edge of right tire and inboard edge of left tire

appeared badly scuffed. Tires were turned 17 degrees to the left as indicated by the rotary placard on rear part of the leg. The scuff marks on the tires were approximately 90 degrees to tire tread centerline.

The upper drag brace lug was fractured. The lock links and lower drag brace were scuffed but intact. The hydraulic tubing and hoses were damaged but not leaking. The actuators were intact and relatively undamaged.

Other damages to the wheel well structure, doors and landing light were observed and were considered to be a consequence of the off-runway run.

A portion of nose landing shock strut smashed into the electronic bay access door and belly structure between this access door opening and aft wheel well bulkhead.

1.16.1.2.2. *Main landing gear*

1.16.1.2.2.1. Right Main Landing Gear (RMLG)

All components of the shock strut and side strut appeared to be intact and undamaged. They were contaminated with large amounts of sand, dirt and other debris. No fluid leakage from the strut was observed.

The tires had a lot of useable tread life remaining on them. The tread surfaces had some abrasions and cuts on them. The brakes had plenty of wear pin length on them. No leaks were observed at the brake pistons. No noticeable damage to the wheels or brakes was observed. The wheels and brakes were heavily contaminated with dirt and sand.

All gear doors and attachment hardware were intact and undamaged, although they were heavily contaminated with dirt and sand.

No damage or leakage was observed on any of the hydraulic system or actuation system components although many components were contaminated with dirt and sand. No fire damage was observed.

1.16.1.2.2.2. Left Main Landing Gear (LMLG)

The shock strut separated from the rear spar and the gear beam attachment points. The forward side separated at the fuse bolt within the trunnion link/trunnion bearing and caused localized damage to the trunnion bearing and rear spar fitting. The aft end separated at the aft trunnion bearing fusible nut, causing localized damage to the landing gear beam. The side strut was still attached to the sock strut. It separated from the airplane structure at the uplock bellcrank and the uplock actuator. The fusible bolt at the

upper end of the drag strut did not fracture. Both the shock strut and side strut were contaminated with large amounts of sand, dirt and other debris. No fluid leakage from the strut was observed.

The tires had a lot of useable tread life remaining on them. The tread surfaces had some abrasions and cuts on them. The brakes had plenty of wear pin length on them. No leaks were observed at the brake pistons. No noticeable damage to the wheels or brakes was observed. The wheels and brakes were heavily contaminated with dirt and sand.

All doors and attachment hardware were severely damaged and heavily contaminated with dirt and sand.

Several hydraulic tubes in the wing root area including both brake pressure tubes were severed, bent or dented. Leakage was observed coming from the severed brake system tubes. Many components were contaminated with dirt, sand and hydraulic fluid. The landing gear actuator, uplock actuator and downlock actuators were damaged, as was the walking beam and the uplock mechanism. No other damage was noted on airplane system components in the MLG wheel well.

Antiskid and lock indication sensor wiring was severed. No fire damage was observed.

The left wing trailing edge had numerous dents in the trailing edge flaps, flap track fairings and upper and lower trailing edge panels as result of contact with the separated MLG components.

1.16.1.3. Engines

1.16.1.3.1. *Left engine*

The inlet cowl was still attached to the engine but severely dented and cracked. All fan blades were damaged, in a way consistent with low thrust foreign object debris (FOD) entry into the inlet. Parts of security netting and plastic (red & white color) barriers were found in fan and stator vane area.

There was evidence of sand ingestion into the core engine. The fan cowling was severely damaged, especially on the RH and underside. The RH side had partly been torn off. The underside showed severe vertical and longitudinal impact damage.

The thrust reversers were found stowed. The underside showed signs of scraping. The RH forward side of the RH fan reverser was partly bent backwards. The pylon fairings were cracked at several places, suggesting deformation to the pylon/wing attachment.

There were signs of deformation on the upper side of the exhaust, which contained some sand. All systems on the lower half of the engine were severely damaged. There was a small oil leak on the LH side, but no fuel leak was observed. No fire damage was observed.

1.16.1.3.2. Right engine

The inlet cowl was still attached to the engine with some minor scratching damage at several places.

Three fan blades had slight damage in the tip area, which was consistent with low power FOD entry into the inlet. There were remains of fire extinguishing agent in the core engine inlet.

The fan cowling was damaged on the underside in which appeared to be a combination of vertical and longitudinal loads.

The thrust reversers were found stowed. The underside showed signs of scraping. The pylon fairings were not cracked. Some sand was found in the exhaust. No evidence of fluid leakage observed or fire damage was found.

1.16.1.4. Electronics Equipment Compartment (EEC)

The left-hand nose wheel had hit the EEC access door when the nose landing gear collapsed rearwards, displacing it upwards and damaging the sliding mechanism, which is normally used to stow the hatch to the right of the compartment after opening it. The nose gear torsion link hinge hit the fuselage just in front of the forward rim of the door opening. The door sill was heavily damaged, the forward rim was severely cracked and the internal structure bent upwards. The locking pins of the door caused damage to all respective rim sides, resulting in sharp edges of torn aluminium. The fuselage skin to the left of the door opening was severely cracked.

The forward rack was bent in an inverted V-shape, with a displacement of approximately 4 cm in the middle of the shelves and no displacement at both outboard ends of the rack. The middle lower shelf below the Flight Control Computer was buckled. No distortion was observed to any of the components present in the racks. Some support rods connecting the shelves were bent.

The left rack, right rack and aft rack, and the wiring did not have noticeable damage.

The battery that is located to the left of the entrance, just forward of the left avionics rack had its support partly bent after having been pushed upwards by the nose wheel.

1.16.2. *Additional detailed inspections*

Several components were reserved for further inspections and test at laboratories. Other systems of the aircraft were subject to on site tests and detailed inspections, with the following results.

1.16.2.1. Steering input as a consequence of a NWS cable failure

As described in 1.6.2.1, the two nose gear steering cables exit the pressurized area of the airplane on the left side of the nose landing gear wheel well. The cables are routed along the axis of the nose landing gear trunnion to the center of the nose landing gear and are turned downward towards the steering mechanism by two pulleys mounted at the top of the nose landing gear shock strut. After the accident it was found that the NWSB (or RH) cable was jammed in the upper pulley, the pulley was broken loose from its mounting bracket, and the cable was broken between the pulley and the pressure seal at the side of the nose gear wheel well. The other cable (LH cable or NWSA) was not broken, but its upper pulley was also found to be jammed (see 1.16.1.2.1).

It was not possible to determine with an absolute degree of certainty whether the NWSA (LH) upper pulley was already jammed before the impact into the ground or, on the contrary, the jamming occurred when the nose landing gear collapsed and several of its components broke and were displaced during the ground roll outside the paved surface of the runway. This second possibility was considered more probable by some of the experts that inspected the aircraft after the accident.

Original information from Boeing stated that a broken NWS cable will result in the nose gear to center. This information was later found to be incorrect. On the accident aircraft the right cable was broken and the nose gear was deflected 17° to the left. The nose gear did not return to its center position.

After the tests carried out by KLM (see 1.16.3), the manufacturer corrected a previous statement regarding the behaviour of the system after a bird impact and stated they suspected that «in the majority of cases where a foreign body impacts a cable, the cable would momentarily deflect and then return to its normal location under its tension, and the steering system would return the nose gear to center. In the PH-BTC event, the immediate cause of the NWS offset was the impact of the bird during takeoff. Either a displaced and jammed cable or a fractured cable can cause a NWS offset».

1.16.2.2. Emergency lighting system

The emergency exit light switch S7 (cockpit) was found positioned in «armed», as well as the emergency exit light switch S538 (aft cabin attendant panel) was found posi-

tioned in «normal». In these positions, the Emergency Light System should have been powered. All circuit breakers were still «active», without evidence that a short circuit had occurred. There were no damages found in the Emergency Light System. The Emergency Light Battery Packs were replaced one at a time and an operational check in accordance with the AMM was performed. The whole system performed as intended.

An Operational Check and Functional Check of the cockpit switch S7, the Attendant switch S538, L1 Emergency Unit Not Armed Light and Circuit Breaker C250 revealed no faults. All equipment and wiring performed as intended.

In summary, after the inspections and tests carried out with the new battery packs, the specialists reached the conclusion that there was no evidence of malfunction of the Emergency Light System. The system should have worked normally at the time of the emergency evacuation after the accident.

According to the information provided by the operator, the eight battery packs of this system that the aircraft had the day of the accident were installed in September 2002. They were scheduled for removal 36 months after installation, which was due at September 2005. The packs had a total of 5522 FH on the day of accident.

An operational check of the interior emergency lights is carried out every 300 FH. The last check on aircraft PH-BTC was performed on 29 October 2004.

1.16.2.3. Flight recording system

The DFDR and CVR wiring continuity and isolation were checked by maintenance technicians. The power to the DFDR and to the ACMS DFDMU was also checked. Those checks did not find any malfunction.

The conditions for the DFDR to start and stop recording were also checked (aircraft on ground and at least one engine running as indicated by oil pressure). The air/ground relay was checked, as well as the low oil pressure switches of both engines.

The relay contacts on the engine accessory units were found to work properly. The wiring from the air/ground relay, engine pressure switches and engine accessory unit to the DFDR test switch connector was found to be in good condition.

The power to the CVR was checked from the circuit breaker on the P18 panel to the CVR connector. All the wiring was in a normal status, and no interruption or short to ground was found.

If during the incident one engine had stopped, the power for the 115 VAC bus 1 should have been taken over by the 115 VAC bus 2 by the power transfer relays. Both relays

and contacts were measured and checked on the aircraft (with all wiring disconnected) and no evidence of malfunction was found.

The power transfer relays were removed from the aircraft and checked in bench by KLM for switching and contact resistance. Both relays passed all the tests.

To look for a possible faulty condition of the generator control units 1 and 2, the latched trigger points were checked to see whether any of them was set. All trigger points were measured with results within limits. Therefore, there were no faults set on both units.

1.16.2.4. Rotational status of the engines at the moment of foreign object ingestion

A boroscope inspection of the engines was carried out to try to identify if there was a cause for an engine flame out due to the runway overrun. The cores of the engines (which were free to rotate) were inspected for dirt, sand or some sort of damage. No serious damage was found in any engine, although some sand passed through the cores during the sequence of the accident. It can be concluded from this inspection that the engines probably did not flame out due to internal damage caused by FOD.

1.16.2.5. Possible pre-existing damage to the NWS system components

The bird remains spread over a large area of the nose landing gear well suggested that the impact of the bird caused the failure of some components of the NWS system, especially the NWSB cable and support bracket of the pulley. To find the pre-accident status of the system, several components were sent to laboratories for detailed inspection.

1.16.2.5.1. Inspection of the broken NWS cable in laboratory

A part of the broken NWSB cable P/N BCRE7631 (of approximately 560 mm of length including the cable terminal) was sent to a laboratory for fracture analysis. The diameter of the cable was 3/32 in (2.4 mm), with 7 strands of each 7 wires. The wire diameter was 0.29 mm, and it was made of 304 stainless steel. The laboratory concluded that the seven wires from the core strand failed by ductile overload. The six outer strands showed severe wear. Approximately 5 wires from each outer strand were worn-through completely; the other wires were thinned severely. Wear damage was observed over a length of approximately 80 mm. No corrosion was observed. Their conclusion was that «It is obvious that severe wear preceded the failure of the cable. The wear of the outer strands was so severe that nearly all load had to be carried by the core strand. A relatively low load was sufficient to cause cable failure».



Photos 1.6.2.1 and 1.6.2.2. Each part of the broken cable was sent to a laboratory

The other part of the broken NWSB cable, together with the broken pulley bracket, was sent to another laboratory. The cable was still stuck against the pulley wheel due to bird remains.

The conclusions of this laboratory were:

«The steering cable fractured by tensile overload of residual cable strands following extended wear damage.

The wear was due to service vibration and rubbing against a pressure seal while exposed to environmental dirt and debris.

The cable met drawing requirements for construction, chemistry and microstructure.»

1.16.2.5.2. Inspection of the trunnion seal in laboratory

The trunnion pressure seal and the NWSA cable (that did not break) were also sent to the laboratory for a detailed inspection.

The laboratory reported that «This cable is severely worn. Many outer wires are severely thinned by wear; some wires are broken as the result of this wear».

The pressure seal was disassembled and it was found that «The plastic material (a glass-fiber/teflon filled polyamide) shows relatively minor wear. Only the entrance and exit locations exhibit some deformed material. All chambers in the seal are filled with grease. Contamination with dirt is evident. Some grease was removed and dissolved to isolate the contaminant. [...] A large fraction consists of sand grains».

The laboratory concluded that «The severe wear is not limited to the broken cable. Both cables are worn at the location where the cables pass the pressure seal. Most likely, the presence of sand grains and other contaminants embedded in the grease was responsible for the wear».

1.16.3. Tests performed by KLM

After the accident, KLM performed actual tests on two of their B737 aircraft by actually cutting the NWS cables to find out what, if any, the resulting steering input would be when one of those cables fails. Before the second test commenced, the rigging of the NWS cables was checked and if required adjusted to Boeing specifications. The results were:

- The NWSA (LH) cable was cut in an aircraft resulting in a steering input of 12° to the right.
- The NWSB (RH) cable was cut in another aircraft, resulting in a steering input of around 20° to the left.

The results were discussed with Boeing, which later acknowledged that a steering cable break would result in a non reversible steering input and that the investigation team had been supplied with the wrong information regarding system behaviour.

They then informed that «Analysis conducted by Boeing shows that the Nose Wheel Steering Angles (in degrees) following a Steering Cable Fracture for 737-3/-4/-5 airplanes are:

Single Tiller: 6.9 Left or 10.9 Right

Dual Tiller: 20.4 Left or 9.3 Right»

All KLM B737 aircraft had a dual tiller configuration.

This happened after the final report of the accident had been published by the CIAIAC.

1.16.4. *Simulator analysis of the aircraft ground trajectory*

The manufacturer carried out a simulator analysis of the accident «to better understand the relationships between the recorded rudder pedal and the heading and lateral acceleration data. An attempt was made to determine the nose gear steering angle required to match the lateral deviation of the aircraft on the ground, presuming the nose gear was jammed at some deflection as a result of the bird strike». The conclusion for this part of the simulation was that «When used with a fixed –11.2 degree left nose gear angle, the simulation shows that the aircraft could have maintained the runway heading until air-speed decreased below about 100 knots. At that point, the nose-left yawing moment due to the nose gear began to overpower the nose-right yawing moment produced by the rudder. This is consistent with the DFDR lateral acceleration and heading data».

«A second simulation was run in an attempt to determine what level of manual brakes was used during the rollout. The simulation takes into account the configuration of the airplane, as described above, including the –11.2 degree nose gear steering angle. It was found that 400 psi symmetric manual brakes (the equivalent to an Autobrake 2 setting) matched the longitudinal deceleration, while at the same time matched the heading and lateral acceleration [...].»

«A third simulation was run in an attempt to estimate what the aircraft's ground track would have been if full right asymmetric braking (3,000 psi) had been used. The simula-

tor was initialized as in the previous simulation that used symmetric reverse thrust, a nose gear steering angle of -11.2 degrees, and 400 psi symmetric braking. [...]. The comparison of the ground track of both the symmetric and asymmetric braking cases to the ground track derived from the FDR shows that the simulation ground track with symmetric braking is similar to the FDR ground track but delayed in the time of departure. This difference may be due to calculation techniques or FDR sample rate issues. In the asymmetric braking simulation, full right braking was commanded at time [17:40:56 h]. The resulting ground track shows that the use of differential braking in addition to full right rudder would have provided enough right yawing moment to control the effects of the jammed left nose gear until the airspeed dropped below about 65 knots, and thus enabled the aircraft to remain on the runway for a longer time. As a result, the airplane would have departed the runway at approximately 30 knots airspeed, as opposed to the 80-90 knots predicted by the symmetric braking simulation and the FDR ground tracks.»

«A fourth simulation, [...], was run in an attempt to estimate what the aircraft's ground track would have been if full symmetric braking had been used as soon as the rudder was saturated. The simulator was initialized in the same way as the previous simulations. [It was compared] the ground track of both the symmetric 400 psi braking case and the symmetric 3,000 psi braking case to the ground track derived from the FDR. The simulation predicts that the application of maximum symmetric braking would have caused the airplane to deviate left at a much higher yaw rate because of increased loading of the nose gear. Despite the quicker deviation, the aircraft would have departed the runway at about the same airspeed of 90 knots, since the application of maximum braking would have caused the airplane to decelerate more quickly after touchdown. A comparison of the simulation runs [third and fourth] indicates that the application of maximum symmetric brakes with the nose gear jammed degrades the controllability of the aircraft.»

The manufacturer concluded that «An engineering simulation analysis suggests that a nose gear steering anomaly was the cause of the event. A simulated nose gear jam of -11.2 degrees to the left, in conjunction with 400 psi symmetric manual brakes (the equivalent to an Autobrake 2 setting), and the DFDR recorded control inputs, resulted in a reasonable match of the DFDR lateral acceleration, longitudinal acceleration, and heading rate, thus validating the scenario from the bird strike theorized during the field investigation».

Boeing informed that they had run the simulation at 17° of deflection of the nose wheels, which was the value found after the accident, but the values of heading and lateral acceleration of the simulation did not match the FDR data.

1.16.5. *Identification of the bird*

On runway 18L at AMS several bird remains were found, including the head of a bird. The identification of those remains led to the conclusion that the bird was a buzzard

(latin name «Buteo buteo»). It was stated that males can weight 700-800 grams and females about 1 kg.

At BCN, the bird control unit of the airport also retrieved remains of the bird from the NLG area and, following their established procedure, carried out the identification of the species with the following results:

It was a «Busardo ratonero» («Buteo buteo»), young, whose sex remained unknown. This species is abundant in great part of Europe. The bird is mainly active at daylight.

1.17. Organizational and management information

Organization of Barcelona Airport as regards to emergencies is described in paragraph 1.10 above.

1.18. Additional information

1.18.1. ICAO bird control program

Paragraph 9.5 «Bird hazard reduction» of Annex 14 of ICAO contains three recommendations dealing with the establishment of a national procedure for recording and reporting bird strikes to aircraft; taking «action to decrease the number of birds constituting a potential hazard to aircraft operations by adopting measures for discouraging their presence on, or in the vicinity of, an aerodrome», and the elimination or prevention of garbage disposal dumps or any such other source attracting bird activity on, or in the vicinity of, an aerodrome.

To deal with the first recommendation, Document 9332 «Manual on the ICAO Bird Strike Information System (IBIS)» describes the reporting system to be used by the States. This system was established by ICAO in 1980. However, it is widely recognized that not all the bird strikes are reported to the national databases of the States or to ICAO.

Guidance to comply with the second recommendation may be found in the ICAO document Airport Services Manual (Doc 9137), Part 3 «Bird Control and Reduction».

Additionally, several private and institutional forums, working groups and national and international committees are active throughout the world to address the issue of huge cost and potential hazard caused by bird activity. The civil aviation authorities or the air accident investigation bodies of several States have also prepared specific bird hazard reduction documents for the benefit of the air transport community.

In summary, extensive literature and bibliography is available for the analysis and proposal of preventive measures regarding bird strike hazard to aviation. Some estimates of the loss of lives due to bird strike accidents in the past give values within the range of 250 to 400 deaths.

However, in spite of all the efforts, several sources show that the number of worldwide bird strikes seems to be increasing as a result of many factors, the most important being the growth of air transportation. There is also no noticeable reduction in aircraft damage cost, due to repairs and replacement of parts (especially affecting turbofan engines) and also to precautionary landings with the subsequent loss of revenue and compensation to passengers.

The IBIS shows that around 90 percent of bird strikes occur at or near airports. ICAO estimates show that around 11 percent of all the bird strikes affect the flight in some way, including a 6 percent of strikes that result in rejected take-offs and precautionary landings.

As an example, in 1999 there were a total of 3,373 bird strikes recorded, of which 177 caused substantial aircraft damage. There were a total of 505 events with damages to aircraft parts recorded that year, and 38% were engines, 25% wing/helicopter rotor, 4% landing gear, 5% radome, 4% windshield, and 3% nose.

The statistics of ICAO for year 2000 showed an increase of bird strikes reported up to 8,454. Ninety per cent of them happened at or close to airports, with 38% of them during the takeoff or initial climb phases and 56% during the approach and landing phases. There was a hull loss (a Cessna 310) and 3% of the strikes caused major damage to the aircraft. Finally, 5.5% of the strikes (470 cases) caused impact on the schedule of the flights, with aborted takeoffs or precautionary landings. Only 2 impacts of buzzards («Buteo Buteo») were reported in year 2000.

It is important to note, for the purposes of this report, that the fracture of the nose wheel steering cables does not appear to be a common damage case in the bird strike documents and reports reviewed.

1.18.2. *Certification requirements*

The Federal Aviation Requirements (FAR) Part 25, Section 571 require that «An evaluation of the strength, detail design, and fabrication must show that catastrophic failure due to fatigue, corrosion, manufacturing defects, or accidental damage, will be avoided throughout the operational life of the airplane. This evaluation must be conducted [...] for each part of the structure that could contribute to a catastrophic failure (such as wing, empennage, control surfaces and their systems, the fuselage, engine mounting, landing gear, and their related primary attachments)».

In particular, «the airplane must be capable of successfully completing a flight during which likely structural damage occurs as a result of (1) Impact with a 4-pound bird when the velocity of the airplane relative to the bird along the airplane's flight path is V_c [design cruising speed] [...]». The requirement has some changes depending on the applicable amendment of FAR-25.

There are other requirements for bird impact in FAR-25 that are not related to this accident.

For example, Section 25.775 «Windshields and windows.» states «Windshield panes directly in front of the pilots in the normal conduct of their duties, and the supporting structures for these panes, must withstand, without penetration, the impact of a four-pound bird when the velocity of the airplane (relative to the bird along the airplane's flight path) is equal to the value of V_c [...]».

The issue is also referred to in Section 25.631 «Bird strike damage» (Empennage structure must be designed to assure capability of continued safe flight and landing of the airplane after impact with an 8-pound bird when the velocity of the airplane (relative to the bird along the airplane's flight path) is equal to V_c [...] Compliance with this section by provision of redundant structure and protected location of control system elements or protective devices such as splitter plates or energy absorbing material is acceptable [...]»).

FAR 25.1309 (Amendment 0 as applicable to the steering system of the Boeing 737-400) stated that «(b) The equipment, systems, and installations must be designed to prevent hazards to the airplane if they malfunction or fail». Later on this paragraph was changed to require that «(b)(1) the occurrence of any failure condition that would prevent continued safe flight and landing [must be] extremely improbable», and the possible modes of failure must include malfunctions and damage from external sources.

The bird strike requirements for turbine engines of FAR-33 are not applicable to this accident.

The FAA provided a brief summary of the certification work that is done for the NWS systems. They informed that «the primary requirement of a nose wheel steering system is that control of the airplane on the ground is maintained. The greatest hazard is generally the inability to retract or extend the landing gear in certain circumstances. A lower level hazard is the loss of steering in certain scenarios on the ground».

«Therefore the primary goal is to evaluate what may create these hazards and to minimize these failures and mitigate them to the greatest extent possible.»

«Within the Federal Aviation Regulations (FAR) there are no specific regulations directed to nose wheel steering systems. However the basic system associated regulations are used. There is also a requirement within the flight sections of the FAR.»

They also stated that, according to their experience, a runway departure as a result of a bird striking the nose gear steering system was considered «a fairly unlikely scenario».

1.18.3. *Similar events in other aircraft*

Information was retrieved on three other events in which bird strikes caused damage to the NLG steering on other Boeing 737 aircraft. In one of the events the bird was large enough to shear the NWS cable and the aircraft came to a halt on the runway. In other case, the nose landing gear steering cable was fouled by a bird impact causing some restriction to the NWS during the taxi-in after landing. In the third case, the bird impact caused the nose gear steering cable snapping, i.e., breakage, and the aircraft exited the right side of the runway coming to a rest with the RMLG and NLW outside the paved surface.

The manufacturer informed that only in one other case a Boeing 737 has departed the runway due to a bird strike in over 100 million flight cycle operations of the fleet. Additionally, nearly identical cable-steering systems are used in other aircraft of the same manufacturer with no runway departures due to bird strikes reported.

1.19. Useful or effective investigation techniques

None.

2. ANALYSIS

2.1. General

The analysis of the information retrieved leads to the following summary of the chain of events that led to the accident:

During a normal takeoff at Amsterdam, the aircraft suffered a strong bird strike during rotation.

The strike probably broke the worn steering cable NWSB. No warning was displayed in the cockpit and no abnormal aircraft behavior was observed by the flight crew.

The bird strike was immediately reported by radio to the control tower of Amsterdam and, later on, to the maintenance department of the operator via an ACARS message. No specific measure was taken or advice provided as a result of those communications. Maastricht ACC later informed the aircraft that small pieces remains had been found on the runway, and that the airport people thought it was a small bird. The crew answered they knew it was not quite a large bird, but added that it might be the remains of the bird were still somewhere in the aircraft.

The cruise, approach and landing phases of the flight were normal. The flight crew did not take any special preventive measure as a result of the bird strike. In view of the effects of the strike on the aircraft, there was no specific measure to be taken or procedure to be applied in the operations manual. Additionally, they had information that it was a small bird and no parts of the aircraft had been found on the runway. All those facts reinforced the idea that the bird strike would probably not have major effects on the aircraft.

During the landing roll at Barcelona, as soon as the nose wheels were on the runway (when the aircraft had between 3° and 1° of pitch up, according to the DFDR data), the aircraft started deviating to the left of the runway axis.

The crew applied increasing right rudder over a period of about 5 sec up to the maximum deflection. This action was initially effective in preventing further deviation from the runway axis, but as the airspeed decreased it gradually became less effective.

Autobrake setting 2 and thrust reversers were used to slow the airplane on landing. The DFDR data showed that the deceleration was typical for autobrake 2 with thrust reverse.

One of the crew members stated that he also applied differential braking, and the other stated that he initially applied differential brakes and shortly afterwards both brakes, but no action seemed to be effective to keep the aircraft straight.

At some point, as an emergency measure, the crew also used the tiller to try steering the nose wheels, even though this control is not supposed to be used at such high speeds according to the operational procedures of the aircraft.

The aircraft exited the left shoulder of the runway at around 91 kt of airspeed and, because the airport was carrying out some construction works, it passed through two steps of around 10 cm of height before entering a zone of loose sand where there were frangible plastic barriers.

The nose and main landing gears hit a buried concrete pipeline that caused the collapse of the NLG and the detachment of the LMLG and induced high accelerations to the aircraft that caused several passenger service unit covers and other ceiling panels to open and to detach, as well as caused overhead bins to open and even thrown a passenger out of his seat.

The unprepared terrain beside the shoulder of the runway had two opposed effects: it introduced high impact accelerations to the aircraft that caused major damage and detachment of some items in the cabin, but on the other hand contributed greatly to the braking of the aircraft that came to a stop just at the edge of a rain drainage canal that could certainly have caused catastrophic damage in the event the aircraft had fallen there.

No evidence was found that the collapse of the NLG caused damage to other systems of the aircraft.

The detachment of the LMLG happened as expected by design (through the breakage of the fuse bolts) and did not cause additional damage to the aircraft, especially regarding fuel tank rupture and potential fire hazard.

After the accident, some difficulties in opening the right hand doors were reported, and the emergency evacuation had to be carried out without using doors 1R and 2R because it was assessed that there was a defective escape slides deployment. This defective deployment was clearly noticeable in the case of door 1R.

The emergency evacuation was found to have been carried out quickly and smoothly, and no major difficulties were reported other than the carriage of carry-on luggage. The fire brigade probably arrived at the wreckage site before three minutes after the alarm sounded.

The post-accident care of the aircraft occupants was perceived as defective, causing uncertainty, disorganization and increasing the stress of passengers and crew. This fact was probably influenced by the fact that the airport and company services had less staff on that Sunday evening than during regular working days.

In summary, it can be concluded that the accident was caused by the impact of a bird of 1 kg or less in weight during takeoff. The weight of the bird, combined with the speed of the aircraft at that moment (around 152 kt) and the local severe wear of the cable, caused an otherwise experienced flight crew to be unable to control the aircraft after landing.

The consequences were several injuries to passengers, huge costs to the airline, including the wreckage recovery costs and the actual loss of the hull, a big impact in a major international airport as Barcelona, with the corresponding delays and costs to several other airlines flights and thousands of other passengers, and with the potential hazard of catastrophic personal damage consequences because the aircraft was about to slide into the canal.

The resources devoted to bird control at AMS could not in the end avoid the accident.

Although the aircraft steering system had a cover to protect it from loose fasteners, mud, stones, slush, ice and other small runway debris, the manufacturer reported that the steering system (including the cover) had not been strengthened to withstand a bird strike, and the severely worn state of the steering cable made it susceptible to failure.

The experienced flight crew and maintenance personnel of the operator did also not consider it necessary to take any action after the bird impact was noticed during take-off.

Although it could be argued that the probability of a similar event happening in the future is very low, it was found that at least three other related events had happened in the past, including the breakage of a NWS cable in two of them. All those facts lead to the conclusion that some preventive measures should be discussed and taken in the shortest possible term.

Other aspects that, although not directly related with the cause of the accident, were initially identified during the investigation were:

- Possibility of malfunction of the emergency lighting system.
- Quality of the recorded DFDR data.
- Usability of the QAR data for the investigation of the accident.
- Detachment of some passenger cabin items and other general aspects of the evacuation, including deployment of the escape slides.
- Suitability of the airport arrangement regarding runway overruns.
- Post-accident handling of the aircraft occupants.

The operator and the manufacturer provided support to the investigation to extract as much as possible safety information from the accident circumstances and from the wreckage layout. The results are discussed below.

2.2. Causes of the fracture of the cable

The immediate cause of the fracture of cable NWSB, as shown by the remains found on the cable and the effects noticed during the landing, was the impact of the bird during takeoff when the aircraft had a speed of 152 kt. The crew stated that they saw a bird coming from the left side of the aircraft. It remains unclear whether the NWSA cable was also substantially displaced by the bird and then jammed in the deflected position at this point. After the accident, the upper pulley of this cable was found to be jammed, but the whole NLG had already suffered substantial damage and collapsed rearwards. Although there were bird remains in several parts of the NLG, it seems improbable that the impact of the bird had affected both sides of the NLG with enough energy at the same time. With the information available after the tests carried out on the system, it is considered more probable that the jamming happened during the off-runway run of the aircraft.

On the other hand, it is considered probable that the brackets of the support pulley of the NWSB cable (see Photo 1.6.2.2) broke after the collapse of the NLG, as shown by the fact that the break surfaces were relatively clean from any bird or dirt debris.

As it has been stated above, the stainless steel NSWB cable was very weakened by extensive wear due to the rubbing against sand particles that had been trapped by lubricating grease produced as the cable passed in and out the pressurized zone through the trunnion pressure seal. This was a known problem and the presence of grease in that area was against the recommended procedures of the manufacturer issued through Fleet Team Digest 737-FTD-32-03008 (last revised: 24 September 2004). The cable had been installed in October 2002, and then inspected in March 2004. The NSWA cable, which did not break, was also extensively worn out. It could not be determined when or why grease was applied to the cables in spite of the FTD and the content of the MPD of the aircraft.

Once this fact was found during the investigation, the operator ordered an inspection of their fleet to detect any seal that was inadvertently lubricated. Additionally, instructions were distributed within the maintenance department to ensure that this practice was discontinued. It is considered convenient to issue a safety recommendation to the operator to review their maintenance procedures to ensure that all the relevant documentation of the manufacturer is followed during the routine maintenance tasks.

It is also considered convenient to remind or highlight the whole issue of worn NWS cables to other operators, given the major impact it could have on the controllability of the aircraft. Therefore, a related safety recommendation is issued.

Some specialists consulted thought that it is probable that the cable would have withstood the bird impact if no wear would have been present. The strength of a new cable is considered high enough to be able to cut the flesh of a bird of around 1 kg of weight without breaking.

In this case there should be a limit of wear below which the cable would not break by the impact of a bird of certain weight at certain speed. However, it would be difficult to determine this limit by analysis or test, because it would not be easy to reproduce in a test or impact model the actual conditions of a bird impact using both new and worn cables. There are a lot of variables playing a role in the impact sequence, including the vertical and horizontal angles of the impact, the actual tension of the cables, the weight and the relative speed of the bird, etc.

However, evidences have been found that similar cables broke due to a bird impact in at least two other cases involving the Boeing 737. Although it is unknown the pre-event status of those cables regarding wear, this sequence of cases shows that fracture of the cables may happen in a variety of circumstances and this leads to think that some kind of protection should be provided to the cables to avoid possible catastrophic effects. Additionally, normal wear would occur in the cables throughout their service life until they are replaced in accordance with the instructions of the maintenance documentation. The safety measures taken should assure that cables end their normal service life being able to withstand certain bird impacts. Finally, even if no breakage of the cable after a bird impact happens, there is still a possibility that the bird remains will jam the pulleys or other parts of the mechanism, which effect could be similar to fracture of the cable.

However, it was considered that no explicit certification requirements existed for protection of this area against bird strikes. The design of the aircraft already had a protection cover of the zone of the metering valve, but the manufacturer reported that it was not designed for bird impact. It is considered that the effect of the fracture of the cables could be similar to the malfunction of the metering valve. In that case, directional control on the ground may be lost at some speeds with full rudder deflection and full differential braking with some degrees of rotation of the nose wheels (as shown both by the circumstances of the PH-BTC accident and by the simulation of the manufacturer). It was thus considered that some sort of protection of the cables (i.e. shielding) and of the metering valve (i.e. reinforcement of the cover) should be provided.

However, the manufacturer informed that in their opinion this protection was either not needed in a no-wear condition of the cables, because of the low probability of breakage in that case, or it was not feasible in practice, because adding a kind of shield would add frontal area that could be hit by a bird and, if deformed, the shield could still increase the likelihood that the cable would be jammed in a deflected state or even be harmful to the system under certain conditions. This could pose other unexpected hazards to the aircraft.

Regarding the cover, although its reinforcement would probably be easier to accomplish than the shielding of the cables, it was argued that it was not damaged during this accident and that no related specific certification requirements existed at the time of its design.

In any case, in view of the risk that may affect several parts of the system, it is considered convenient to issue a safety recommendation to the certification authority in order to review the requirements to assure that similar future designs, when applicable, are protected against bird impacts.

2.3. Effects of the fracture of the cable

The effect of the breakage of the cable was not noticeable after the bird impact since the aircraft was already lifting off the NLG from the runway surface. Although it could be argued that some doubt exists on whether the NWSA cable was jammed against the pulley at that point, the corresponding discussion would have no practical effect because the nose wheels would have been rotated anyway regardless of the jamming status of the pulleys.

Then there was a normal retraction of the landing gear. During gear retraction, hydraulic pressure would be removed from the steering system and the nose wheels would be held in the centered position by the centering cam. When the gear was lowered during the approach to BCN, the steering system would be pressurized. If the steering actuators had sufficient force to overcome the centering cam, the nose wheels would have rotated to the left. Otherwise the nose wheels would have remained in the centered position until the centering cam was disengaged due to compression of the nose landing gear on touchdown, allowing the nose wheels to rotate to the left. As soon as the nose gear touched the runway surface, the veering of the aircraft to the left started. This resulted in a powerful effect that could overcome the rudder effect as the aircraft slowed and the rudder became less effective.

The fracture would have caused no effect when the rotation of the tiller was intended to the right as was the case according to the statements gathered. This was the effect noticed by the crew when they used the tiller after the other actions did not have any effect in arresting the deviation. Even though this action was not allowed by the standard aircraft operational procedures of the aircraft, the crew tried to use any possible means to solve the emergency situation they faced in the short period of time they had available. DFDR data shows that around the time the aircraft left the paved runway surface, the reversers were stowed. From the interviews with the crew it does not become clear that the crew deselected reverse thrust willingly. It could very well have been the result of the high (vertical) accelerations present at the time the aircraft left the runway. As the pilot has his hand on the thrust reverser lever (holding it up) during reverse action, the vertical accelerations could have forced his hand (and the reverse lever) down to the STOW position.

In addition to application of right rudder, another significant means to reduce the rate of deviation would have been the use of heavy differential braking as soon as possible. It was not possible to determine the actual brake pressures achieved during the

landing roll, because these parameters are not recorded in the DFDR and the data of the QAR were lost for the latest part of the flight. However the DFDR longitudinal acceleration data shows that braking equivalent to autobrake 2 with thrust reverse was applied for most of the landing rollout. The simulation of the manufacturer concluded that 400 psi symmetric manual brakes (the equivalent to an Autobrake 2 setting that was the value selected during the approach) matched the longitudinal deceleration. There was no evidence of any possible brake malfunction during the landing roll.

The left and right main gear tires left marks on the runway (see Appendix A) that first appeared for the LMLG tires (246 m after the start of the NLG marks) and 132 m afterwards for the RMLG when the NLG was already close to crossing the white side stripe line. These marks were steady, though, and did not exhibit the intermittent characteristic that results from the small tire skids and brake releases normally seen when the antiskid system is modulating brake pressure. It is most likely that the tire marks resulted from a lateral slip angle of the main gear tires in reaction to the steered nose wheels and the applied rudder, although this effect would also have deleted any marks of the antiskid system action.

The DFDR heading data shows that the airplane longitudinal axis remained parallel with, or slightly to the right of parallel with the runway axis until just after 17:40:58. This difference between direction of travel of the aircraft and the heading of the aircraft would produce a slip angle at the tire/ground interface which would generate the tire marks observed. Application of full right rudder would impose a rolling moment to the left on the aircraft and would account for the fact that the marks of the LMLG tires appeared before the marks of the RMLG.

One of the crew members stated he used differential braking to the right, while the other stated he initially used differential brake to the right and shortly afterwards, when he realized the aircraft would exit the runway surface, he applied symmetrical braking while still maintaining full right rudder. The combined effects of those inputs would have been no differential braking, because the greater of the commands to each pedal would be applied to the brakes. The DFDR longitudinal acceleration data indicates that the crew did apply full pedal braking (3,000 psi of brake pressure, as opposed to 400 psi with autobrake 2 setting), but this braking was not applied until just prior to the aircraft leaving the normal paved surface of the runway.

In summary, due to the lack of recorded brake pressures in the DFDR, to the sampling rate of the some DFDR parameters like magnetic heading (1 value per second) and the possible masking of antiskid marks by the tire skidding marks, it is considered difficult to estimate the exact point on the runway where full manual braking was applied.

The technical information gathered and the simulations performed by the manufacturer seem to point out that in the event of a NWS failure similar to the one described in

this report, the aircraft will most probably exit the side of the runway even if rudder and differential braking are applied, although the speed at the time of crossing the runway shoulder will be reduced if appropriate actions are promptly taken in the cockpit. The actual speed at the moment of departure would be very difficult to predict. In this case, the aircraft exited the runway at a relatively high speed. The manufacturer stated that according to their simulations, a nose wheel deflection of -11.2° to the left would match the runway marks and FDR data. The use of effective differential thrust reverse to regain directional control seems difficult in view of the short available time (8 to 9 seconds in this case since the nose wheels touched down to the moment the aircraft exited the runway).

In view of these circumstances, when neither the experienced flight crew nor the ground maintenance technicians that were informed about the bird impact considered necessary to take any precautionary measure during the flight (especially taking into account the information about the small size the bird apparently had), combined with the fact that the possible malfunction of the NWS system was not identified on time by the crew during the landing roll, it is considered necessary to issue two safety recommendations.

Information should be provided to all the operators to make them aware of the effects of a broken cable (because of a bird impact or of whatever other reason) could have on the nose wheel steering system. Additionally, further information or training should be provided to flight crews to let them know that some degrees of nose wheel steering rotation could have a major impact on the directional controllability of the aircraft and to be able to take quick corrective measures in that case, reminding them the need to use heavy differential braking.

During the investigation it became apparent that a nose wheel steering cable failure caused by a bird strike was not an isolated case. Two other confirmed cases of cable failures caused by a bird strike have been documented. The wear state of the steering cables was not reported in those cases.

Contrary to earlier information from Boeing, it was found that a NWS cable break will result in a nose wheel steering input even if the cable is not jammed in a deflected state. On a dual tiller aircraft (like the accident aircraft) this could go to 12° to the right when the NWSA cable breaks, and up to 20° to the left when the NWSB cable breaks, as shown by test. This means that with this new information, there is a higher probability of the aircraft having major problems during the landing regarding directional controllability, because there is no need that the cable gets jammed to cause the permanent deflection of the nose wheels.

The information gathered seems to point out that this kind of failure was considered only a «major» failure at the time of original type certification, minimizing to some point the effects of a runway excursion at high speed. However, the outcome of this acci-

dent, and the fact that the aircraft will almost certainly exit the runway in the event a cable of the NWS system breaks (which is more probable than a breakage and then a jamming), would make it advisable to take preventive measures.

Several possible safety recommendations were evaluated before the issuance of issue 2 of this report, including the possibility that the manufacturer provided operators with appropriate means to allow flight crews to detect a possible fracture of the cables, and provided an operational procedure to minimize the effects on the aircraft during take-off or landing in such a case.

These recommendations were finally not issued in view of the fleet service experience and the practical feasibility of the measures.

However, it is considered practical in terms of safety benefit to carry out a thorough revision of the details of the design of the system to try to correct the cause of the deflection of the wheels in the event of the cable fracture, in order to avoid that such a failure jeopardizes the directional controllability of the aeroplane. Therefore, a safety recommendation is issued in this regard.

Additionally, it would be advisable that the manufacturer inform the flight departments of the operators of B737 in the appropriate way of the consequences of a NWS cable fracture (even when the cable is not jammed) in terms of nose wheels deflection and subsequent probable runway excursion. Therefore, another safety recommendation is issued in this regard.

2.4. Flight recording system

The CVR is powered by the 115 VAC Electronic Bus 1 and as long as there is 115 VAC available it should continue to recording data. The CVR stopped recording sounds approximately at 17:41:06 h. It was initially considered that maybe the recorder ended before the aircraft had come to a complete stop and the engines had been shut down, although it is unknown if the engines flamed out due to some kind of damage as there is no supporting FDR data or other factual information. It is unknown the spool-down time of the engines after normal shut down by the crew or after a flame out due to some kind of damage.

The system was inspected by the operator and the manufacturer, in an attempt to identify what kind of damage, if any, the off-runway run had caused to the system (especially given the fact that the collapse of the NLG had caused damage to the avionics bay located immediately aft of the NLG well). The conclusion of the inspection was that the damage did not directly affect the system and the reason for the stop of the recording was due to loss of the 115 VAC Electronic Bus 1. However the cause of loss bus remains undetermined without supporting data.

The DFDR is also powered by the electronic 115 VAC bus 1 and, as long as there is oil pressure of an engine on ground, it should be powered and continue recording data. In this case, a lot of spurious values of parameters were recorded when the aircraft exited the paved surface of the runway. After 17:41:03,500 h the DFDR data is considered invalid and should be disregarded. Therefore, it was not easy to exactly determine when the recorder stopped recording data.

In any case, whether it stopped before or after the engines were shut down, the detailed inspection of the DFDR system did not reveal any malfunction or abnormal behavior. However, the recorder device itself was faulty to some extent, because, due to the wear status of the tape, a lot of data dropouts happened during the flight. Maybe this situation also led to the recording of more spurious data than normally expected during an off-runway run. FAA Advisory Circular AC 20-141 «Airworthiness and operational approval of DFDR systems» states that a schedule must be established for accomplishing an operational and functional ground check at intervals not to exceed 12 calendar months. ICAO Annex 6 and European Organisation for Civil Aviation Equipment (EUROCAE) documents ED 55 and ED 112 also recommend an annual check of the quality of the recording. However, no life limit of the tape is specified.

The recorder had been installed in the aircraft on 16 May 2003, and it had 4001 h of time since overhaul (TSO). According to the operator, the device was required to be inspected «on condition». They informed that its maintenance had been carried out in accordance with the manufacturer recommendations. The operational check supposed to be carried out every 1C inspection should have detected that there could be data dropouts. According to some specialist's opinion, it is normal to see that kind of wear in tapes of such a long service life (more than 4,000 h in this case). In view of the circumstances of this accident, it seems that some sort of replacement and overhaul period for the recorder should be established to assure that its mission (to provide accurate information of an accident or incident, including the last part of the event) is accomplished during its whole service life. A safety recommendation is issued in this regard.

Regarding the QAR of the aircraft, the corresponding data of the last part of the flight (when the aircraft was at about 224 ft of radio-height) were not recorded. Efforts were made to check whether those data were still stored in the non-volatile memory of the DFDMU, but there was no success. It has to be reminded that QAR is intended for maintenance and operational monitoring and not for accident investigation purposes, and therefore its recorded data (that has more parameters than the DFDR) is not protected against impact, fire, etc.

According to the information gathered, during a normal approach and landing the data is written and stored to internal solid state memory to be later transferred to the optical disk. This may happen after the aircraft is parked for about 5 minutes, to improve the quality of the recording to the disk with minimal vibration. However, this process

has the hazard that if some malfunction happens during the landing or taxi to the apron, the important data of the approach, touchdown and landing roll will be lost. This was the case in this accident and brake pressures, electrical powering and other very important data relevant to the circumstances of the accident were lost.

The conflicting aspects remain for the QAR should a continuous recording be required (losing all the data if an accident happens due to buffer erasing versus losing some data in normal landings due to vibration during recording). Although the QAR is not installed for accident investigation, it is a powerful element and efforts should be made to take as much advantage as possible of its recorded data. However, even taking into account that somewhat higher probability exists for items relevant to maintenance and incident investigation to appear during touchdown and landing roll, it is not warranted the issuance of a related safety recommendation to study the possibility of writing the QAR data continuously during the landing phase.

2.5. Cabin safety and evacuation of the aircraft

Since there were a lot of spurious DFDR data recorded in the last part of the flight, it is unknown the maximum values of acceleration achieved during the off-runway run of the aircraft. The NLG and LMLG hit a concrete underground pipeline and the left leg of the MLG detached after the fuse bolts broke. The NLG collapsed rearwards after the drag link broke.

Therefore, it is estimated that the aircraft suffered important vertical, lateral and longitudinal loads at that moment, although it remains undetermined whether the limits of 9 g forward, 3 g upward and 3 g sideward on the airframe, specified by FAR 25.561, were exceeded inside the fuselage. This regulation requires that under those loads each occupant must be given every reasonable chance of escaping serious injury in a minor crash landing and also the items of mass of the passenger cabin must not deform in any manner that would impede subsequent rapid evacuation of occupants. In this case, it seems that both requirements were complied with, because only minor injuries were produced by the impact and the subsequent emergency evacuation and because there is no evidence that the rapid evacuation was impeded by the loose items of mass (PSU covers, ceiling panels, meal trays, open overhead bins, etc.) The manufacturer informed that interior components including the PSU latches were designed to the following accelerations: forward 9.0 g, aft 1.5 g, upward 3.5g, downward, 6.5 g, side, 3.0 g.

However, in view of the number of items that were disrupted in the cabin, which could have either caused direct injuries to occupants or to have affected the evacuation rate in the event that a quicker rate had been needed (for example, if there had been fire or panic would have appeared), it was suggested that some additional measures could be taken to better restrain the ceiling panels and the PSU covers.

Several latches were found broken after the accident (see paragraph 1.15.1 above), and the lanyard of the ceiling in the forward cabin attendant compartment also broke. The latches of the rear and forward ceiling panels did not break. It seemed that they just opened under the loads induced inside the cabin, as it happened with several overhead bins according to the passengers statements.

It was analyzed whether it was necessary that the lanyards and latches were reinforced to avoid their breakage or release in the event of a minor crash landing. However, the manufacturer stated that, since there were no reliable accelerations recorded by the FDR approximately 2 seconds after the airplane left the runway, it is unknown the loads that were introduced when the LH MLG separated and the NLG collapsed during the impact with a buried pipe line, and therefore the circumstances of this event cannot be properly evaluated. It is possible that the resultant loads from impact with the pipe did exceed the design load limits of the latches. Additionally, the manufacturer did not have a history of anomalies with these latches, which are used quite extensively on 737 and 757 airplanes.

The rear cabin attendant compartment ceiling panel released from its lanyard, whose hook was not at the normal position when the aircraft was inspected after the accident. It is possible that this abnormal position caused a slack that released the lanyard after the latches opened. Therefore, it is considered necessary that the operator inspect their fleet to ensure that in the ceiling panels of the cabin attendant compartments the hooks are located at the appropriate position in the middle of the lanyard assembly.

A meal tray was found down in the egress path to the forward left hand overwing exit. The restrain pin was found to be on the aisle side of the seat back (see Photo 1.15.1.1). This arrangement could cause the meal tray to be easily released during the normal movements of the passengers towards the emergency exit. In a case of rush due to panic, even a minor factor like this one could cause the passengers to jam against the exit. As a result of past accidents in which this fact was found a factor in the personal damages suffered, the European Conference of Civil Aviation issued Document N° 18 which, among other cabin safety issues, stated: «Folding tables in the back of the seats that are not needed should be removed or rendered inoperative. In case they are operative on seats along the access route to the emergency exit, their locks must be sufficiently reliable and adequately protected to prevent their inadvertent release».

The manufacturer informed that they also had similar criteria for the design and installation of seats. Several States included this requirement in their operational inspections of passenger transport aircraft. The CAA of The Netherlands informed that they had been requiring compliance with Document N° 18 for a long time. However, in view of the findings of this accident, it is considered convenient to recommend that similarly registered aircraft are inspected in accordance with this requirement. On the other hand, it was stated that the JAA Cabin Safety Steering Group (CSSG) had been working on requirements for type III exits to be included in JAR 25, JAR 26 and JAR OPS-1, similar to those con-

tained in ECAC Doc 18. Therefore it would also be convenient that EASA and the JAA expedite their work to finalise the upgrade of the Type III exit related requirements that are already in preparation for CS-25 (EASA), JAR 26 and JAR OPS-1 (JAA).

At least one cabin attendant reported that the opening of a door was difficult because it felt very heavy. Additionally, in the four doors problems to latch them open seem to have been faced by the cabin attendants. This was probably due to the left roll angle and the pitch up angle that the fuselage had. It is considered convenient that this fact is further highlighted by the operator during the training of their cabin attendants. Additionally, the cabin attendants stated that if only one cabin attendant is present in the forward or rear compartment and a door becomes inoperative, he/she could not probably move to the other door due to the presence of passengers in panic unless they were retained by a second attendant.

The slide of door 1R did not deploy as expected. It was twisted and prevented its use during the evacuation. This situation was already known by the aircraft manufacturer and the slide vendor, and the manufacturer had a Fleet Team Digest in place to advise of this fact (the first issue of the FTD was December 2002). The malfunction was likely caused by the escape slide being delayed inside the slide compartment. The manufacturer was working in a solution to correct the situation. It is considered necessary to issue a safety recommendation to make the corresponding modification mandatory when available.

Door 2R was not used for the emergency evacuation. The cabin attendant who opened it thought that it was not properly deployed, because she felt the slide was somewhat angled backwards. The slide was found to be displaced laterally (towards the rear of the aircraft) so that the forward support cushion of the slide partially obstructed the aft service door exit. However, no evidence of malfunction was reported as found on this slide when inspected after the accident.

Several cabin attendants commented they did not remember the status of the emergency lights. Several passengers confirmed in the questionnaire (see below) they saw floor path lighting. The captain was sure that there was no emergency lighting in the cockpit, and in his opinion there was at least a partial failure in the emergency lighting system.

The statements that the emergency lights were off and that it was very dark both in the interior and the exterior of the aircraft could not be confirmed by the detailed inspection and tests of the aircraft after the accident. The system was checked to be fully functional with new battery packs. The batteries installed during the accident were inside their service periods. If there was a partial failure of the system, it remained undetected.

An effort was made during the investigation to retrieve as much information as possible regarding the behavior of the passengers during the evacuation. Questionnaires were

sent to all the passengers through the operator. The aircraft had 140 passengers (out of a maximum seating capacity of 147) and was almost full with a lot of carry-on baggage in the cabin. A study of the completed questionnaires is included in Appendix B.

It was not possible to determine exactly the time it took to evacuate the aircraft. From the ATC communications record, it can be stated with certainty that in less than 2 min 26 s all the passengers were outside the fuselage. They had used the four overwing exits and exit 1L and 2L. Two exits (1R and 2R) were never used. The presence of the canal made the use of exit 1L more difficult, and several passengers fell to the water. It was considered that the status of the spoilers panels did not affect the emergency evacuation of the passengers that used the overwing exits.

The statements gathered show that the passengers opened the overwing exits without any problem and it seems that some of them were outside the aircraft even before the emergency evacuation was commanded. The cabin attendants provided the instructions in loud voice (without megaphones) in English and Dutch languages. Communication problems seemed to be present since some passengers did not understand any of those languages, but they just followed the other occupants.

A lot of passengers took baggage and personal items with them despite of the commands and instructions of the cabin attendants. This somewhat delayed the evacuation. Passengers that did not take anything with them considered unfair that the risk was increased because of others taking luggage. There was an unaccompanied minor on board, who evacuated the aircraft with the help of a passenger, and several other children and babies, who were evacuated by their parents. Several passengers had previous aeronautical experience and their command of the situation and their help were very appreciated by others.

It seems that no specific preflight instructions had been provided to the passengers regarding the need to leave behind carry-on luggage in the event of an emergency evacuation. The safety on board cards available to the passengers did not provide that instruction either. Although the cabin attendants commanded (in loud voice, without a megaphone) everybody not to take personal items, it is possible that some passenger did not hear that command or, even if they heard it, decided to imitate others that were taking items anyway. It is difficult to think of a safety recommendation that could avoid a similar situation in the future, because if no panic is present and no signs of fire or other hazards are perceived by the passengers, some of them could tend to think of the emergency evacuation as an abnormal but not urgent way to leave the aircraft, and more importance would be given to taking personal items under those circumstances to avoid future annoying arrangements to recover them. Two possible low cost measures could be to include that instruction in the safety board cards available to every passenger, in the preflight safety briefing and in the voice messages provided during the emergency evacuation, and a safety recommendation is issued in this regard.

The main comments gathered, apart from the fact that personal items were taken before the evacuation, were that it was very dark both inside and outside the aircraft. As it has been stated above, it is very probable that the emergency lighting system was on and worked correctly, but even in that case a lot of statements mentioned the abnormal darkness. Other comments were that evacuation voice commands should be louder and more languages added.

2.6. Suitability of the airport arrangement

Major construction works were being carried out on the strip of runway 25R-07L during the previous days to the accident. Several NOTAMS had been in place for months advising about this fact. Part of the old runway strip was being compacted and other part covered with asphalt.

The width of the strip of runway 25R was 120 m according to the AIP. There was a wide rain drainage canal at around 107 m from the runway axis running in parallel with part of the runway length. Therefore, the canal was outside the declared strip, in which certain requirements of fixed and mobile obstacle placement and maximum slope are supposed to be applicable.

However, in accordance with Annex 14 of ICAO, for an airport code number 4 as Barcelona was, the width of the strip should be at least 300 m (150 m on each side of the runway axis). This strip should provide a graded area (with a maximum slope of 2.5%) within a lateral distance of 75 m to minimize damages in the event of an airplane running off the runway.

Therefore, the canal would be outside that graded area even if the strip was wider than the 60 m on each side declared by Barcelona Airport. However, another recommendation of Annex 14 stated that the rest of the strip should have a maximum upslope of 5% measured in the direction away from the runway. It is obvious that the walls of the canal exceeded that recommended maximum upslope and posed a hazard to aircraft running off the runway in a zone inside the theoretical strip required by ICAO.

The information gathered shows that Barcelona Airport had had flooding problems in the past following heavy rain storms. The size and position of the canal had been calculated to solve that problem.

It is a known problem that airports cannot always comply with the requirements of Annex 14 unless huge costs are faced. In this case, the covering of the canal would mean a major investment and the corresponding impact in the operations of the airport during the time the construction works were being carried out. However, the hazard posed by the canal over large transport category airplanes running off the runway at

high speed makes necessary to think of possible solutions or alternative preventive measures and a related safety recommendation is issued.

Other non-compliances with the guidance material included in Annex 14 were the steps between the different asphalt zones and the unprepared terrain on the left side of runway 25R; the presence of the concrete pipeline that was buried around 20 cm instead of at least 30 cm below the strip surface as mentioned in the Attachment A of Annex 14; and the differences in bearing strength of the strip faced by the aircraft once it left the surface of the runway.

These three factors induced high accelerations on the aircraft causing damage to the landing gear and to the interior of the passenger cabin, increasing the potential hazard of personal damages.

However, the third factor (difference in strength) had also a very beneficial effect because the loose sand contributed to decelerate the aircraft and to bring it to a stop before the canal was reached, which would probably have had catastrophic effects on the occupants.

This difference of strength, the depth of the buried obstacle, and the non-flushed steps that were present in the strip may be attributed to the construction works being carried out, which had been notified by NOTAM, and it is considered that it was very difficult that those issues were overcome before the works were finished.

2.7. Emergency plan at Barcelona Airport

Barcelona Airport had a detailed emergency plan in place at the time of the accident.

However, the information gathered shows that the airport personnel and also the staff of other companies working there did not have it readily in mind. It is possible that, due to the limited extent of the injuries suffered by the aircraft occupants, it was decided not to apply the emergency plan and therefore the passengers were taken to a normal lounge of the terminal instead to the dedicated room on Módulo 0 of the airport. This caused confusion and frustration to the occupants who, in a stressful situation and still under the emotional impact of the accident, were mixed with passengers that were supposed to take the flight back to AMS. Additionally, there was no clear command of the situation, insufficient staff with adequate English language command was present, and first aid items as blankets or water were not available. Some people had wet clothing because they fell to the canal. Some passengers even reported difficulties to make phone calls to their relatives, because they did not have their mobile phones after the accident. The passengers were also worried about their personal belongings still inside the aircraft, whether in the passenger cabin as carry-on luggage, or in the cargo compartments.

After the passengers were taken to the terminal, it is possible that the airport staff concentrated mainly in the aircraft wreckage and the impact in the airport operations caused by the closing of runway 25R. Big delays of the scheduled flights started to appear and it is possible that the organization of the passengers was not the highest priority in the belief that the airline and handling companies would already be taking care of that issue. The last training drill provided regarding the application of the emergency plan was carried out on 7 June 2003.

In view of the situation, it is considered necessary to recommend to AENA that the airport emergency plan is reviewed to be sure that it includes all the details for the adequate care of the passengers after an accident or incident, even if no serious injuries are reported, and that the applicable airport and airline staff of the airport are provided with periodical refreshment training to be sure that the plan is automatically and efficiently applied as soon as an accident happens.

3. CONCLUSION

3.1. Findings

- The aircraft had a valid Certificate of Airworthiness.
- The mass and centre of gravity of the aircraft were within the prescribed limits.
- The pilots had valid licenses and were adequately qualified for the flight.
- There was no evidence that incapacitation or physiological factors affected the flight crew performance.
- The aircraft suffered the impact of a buzzard bird on the nose landing gear during rotation during the takeoff from AMS.
- The bird strike was noticed by the flight crew who informed AMS ATC and their company maintenance department.
- No malfunction of any aircraft system was noticed during the rest of the flight until the landing on runway 25R of BCN.
- The flight crew was informed by the ATC that only small pieces of a bird had been found on the runway at AMS after the bird strike.
- No specific caution or preventive measure was required to be taken according to the aircraft manuals or operational documents in a similar case as the one faced by the crew.
- As soon as the nose landing gear touched the runway surface, the aircraft started deviating to the left of the runway axis.
- The crew applied right rudder but was unable to keep the aircraft from leaving the paved runway surface.
- There is no evidence that the combined pedal actions of the crew produced a heavy differential braking to the right.
- The first tire marks to appear on the runway were due to the LMLG tires.
- The aircraft exited the left side of runway 25R at around 91 kt of airspeed (87 kt of groundspeed).
- The NWSB cable was found broken after the accident. Both the NWSB and NWSA cables were found to have extensive wear caused by rubbing against dirt debris caught by grease applied to the trunnion pressure seal.
- There were maintenance documents of the manufacturer of the aircraft that advised that grease should not be applied to the cables because contaminants captured by the grease could accelerate the wear of the cable.
- The inspections carried out after the crash did not reveal evidence of any malfunction or defect of the aircraft braking and spoiler systems.
- After the accident, both cables NWSA and NWSB were found jammed at the pulleys located on the top of the nose gear shock strut. It could not be determined whether they were jammed before the accident, although it is considered more probable that the jamming happened after the aircraft departed the paved surface of the runway.
- During the original investigation, the manufacturer incorrectly informed that after a NWS system cable fracture, the nose wheels would deflect in some way and then

would return to a centered position unless the cable is jammed in the deflected position.

- This information was incorrect as shown by an actual test carried out. The manufacturer subsequently concurred with these results.
- The fracture (for any cause) of a NWS cable on a dual tiller aircraft (like the accident aircraft) will result in a nose wheel deflection of up to 12° to the right when the NWSA cable breaks, and up to 20° to the left when the NWSB cable breaks.
- A landing with a broken NWS cable will almost certainly result in a runway excursion regardless of the actions performed by the crew, although the exact speed at the moment of departure will depend on several factors. It is not necessary that the other cable is jammed for this outcome.
- The inspections carried out on the emergency lighting system and the cockpit voice recording system did not reveal any pre-accident defect or any damage caused by the off-runway run that could have caused their malfunction before the aircraft came to a stop.
- The inspections carried out on the flight data recording system did not reveal any pre-accident defect or any damage caused by the off-runway run that could have caused their malfunction before the aircraft came to a stop. However, the status of the DFDR tape recording mechanism and tape caused some losses of data through the flight.
- The LMLG leg detached shortly before the aircraft came to a complete stop, when the fuse bolts broke.
- The escape slide of door 1R was twisted after deployment, which rendered that exit unusable for the emergency evacuation.
- The restraining system of the meal table of seat 10B, in front of the escape path towards emergency exit O1L, could easily be released due to brushing during the emergency evacuation.
- There were a lot of witness statements regarding deficiencies in the after-accident care of the occupants of the aircraft.
- The strip of runway 25R of BCN had 120 m of width, while the minimum width established in Annex 14 of ICAO is 300 m.
- Due to the construction works being carried out, the strip of runway 25R of BCN did not comply with the recommendations of Annex 14 of ICAO regarding the flush with the shoulder and the minimization of differences in load bearing capacity between the runway and strip surfaces.

3.2. Causes

It is considered that the accident probably happened because during the takeoff a bird strike broke one of the cables of the nose wheel steering system of the aircraft, which made that the nose wheels were rotated to the left during landing, causing a veering to the left that could not be arrested by full rudder deflection as the aircraft decelerated. The subsequent application of brakes and other actions by the crew could not avoid that the aircraft went outside the runway surface.

The damages to the aircraft were increased by the condition of the runway strip due to the airport construction works.

Contributing to the breaking of the cable was the fact that it was severely worn locally. The wear could be traced back to the incorrect application of grease to the cable system during maintenance. Despite the training and experience of the flight crew, they were unable to quickly recognize the possible cause of the deviation of the aircraft and to keep the aircraft on the runway.

4. SAFETY RECOMMENDATIONS

After the accident, the operator put in place a plan to inspect all the NLG trunnion pressure seals of their Boeing 737 fleet, in order to find out whether grease had inadvertently been applied.

The following safety recommendations are issued as a result of the investigation:

- REC 20/05.** It is recommended to The Boeing Company that a service information letter or similar document is sent to all the operators of Boeing 737 aircraft to make flight crews and maintenance personnel aware of the hazardous effects that a bird impact in the area of the NLG could have in the nose wheel steering system, and that precautionary measures should be taken in this case. This letter should also highlight the importance to strictly follow the instructions of document 737-FTD-32-03008 in order to avoid the wear of the NWS cables.
- REC 21/05.** It is recommended to The Boeing Company that supplementary training instructions are provided to operators of Boeing 737 to allow flight crews to quickly identify a possible NWS malfunction during landing and to advise them of the expected performance of the aircraft and of the measures that should be taken to avoid losing directional control at high speeds.
- REC 22/05.** It is recommended to the FAA that a life limit is imposed to overhaul flight data recorder devices similar to the one involved in this accident to assure that there will not be data drops in their recordings during the time between overhauls.
- REC 23/05.** It is recommended to KLM that the ceiling panels of the forward and rear cabin attendant compartments of similar aircraft of their fleet are inspected to ensure that the S-hook of the lanyards is located at the appropriate position in the middle of the lanyard assembly.
- REC 24/05.** It is recommended to KLM that during the training provided to the cabin attendants of Boeing 737 aircraft more emphasis is placed in the expected difficulties that may be encountered in opening and latching open the doors during a real emergency evacuation due to the roll and pitch angles of the aircraft fuselage. Force needed to open the training door must be brought in line with the force actually needed in an emergency operation.
- REC 25/05.** It is recommended to KLM that the instruction to the passengers to leave personal belongings on board the aircraft in the event of an emergency

evacuation is further highlighted during preflight safety briefings and included in the «Safety on board» card and in the voice messages provided during the emergency evacuation. The possibility of using different languages for these purposes, depending on the route being flown, should be assessed.

REC 26/05. It is recommended to the FAA that the expected modification of the escape slide of door 1R of Boeing 737 aircraft to avoid the twisting of the slide after inflation and deployment is made mandatory for all the affected aircraft when it becomes available.

REC 27/05. It is recommended to the FAA that the requirements of FAR-25 are reviewed to ensure that, when feasible, parts of the nose wheel steering system susceptible of bird strike damage that could pose a major hazard on the aircraft are adequately protected against such impacts.

REC 28/05. It is recommended to the Civil Aviation Authority of The Netherlands that similar aircraft as the one involved in the accident are inspected to ensure that the passageways to type III overwing emergency exits comply with the content of Document N° 18 of the European Conference of Civil Aviation regarding the reliability and adequacy of the locks of the folding tables in the back of the seats.

REC 29/05. It is recommended to AENA that measures are taken in the strip of runway 25R of Barcelona Airport either to comply with the content of Annex 14 of ICAO regarding width and maximum slopes or to reduce the hazards to aircraft running off the runway to an acceptable level.

REC 30/05. It is recommended to AENA that a refreshment training plan is put in place to be sure that the emergency plan of Barcelona Airport is immediately and efficiently applied in the event of an accident. The training should cover all the details of the after accident care of the aircraft occupants.

After the first issue of the report was published it has been found that when a NWS cable breaks it will probably cause a runway excursion (even if the broken cable is not jammed). Therefore, the following safety recommendation is issued in this second issue of the report:

REC 25/07. It is recommended that the FAA requires Boeing to review the design of the B737 to ensure that a fracture of a NWS cable will not result in a deflection of the nose wheels that could cause a hazardous situation.

In response to safety recommendation 20/05, Boeing stated they had issued a Multi Operator Message (ref. 1-111721075, dated 10-August-2005) to inform B737 operators of some facts regarding the accident. However, this document does not cover the new facts described in issue 2 of this report. Additionally, this type of document is mainly used to communicate technical issues to operators. The operational issues are normally covered by other type of communications of the manufacturer.

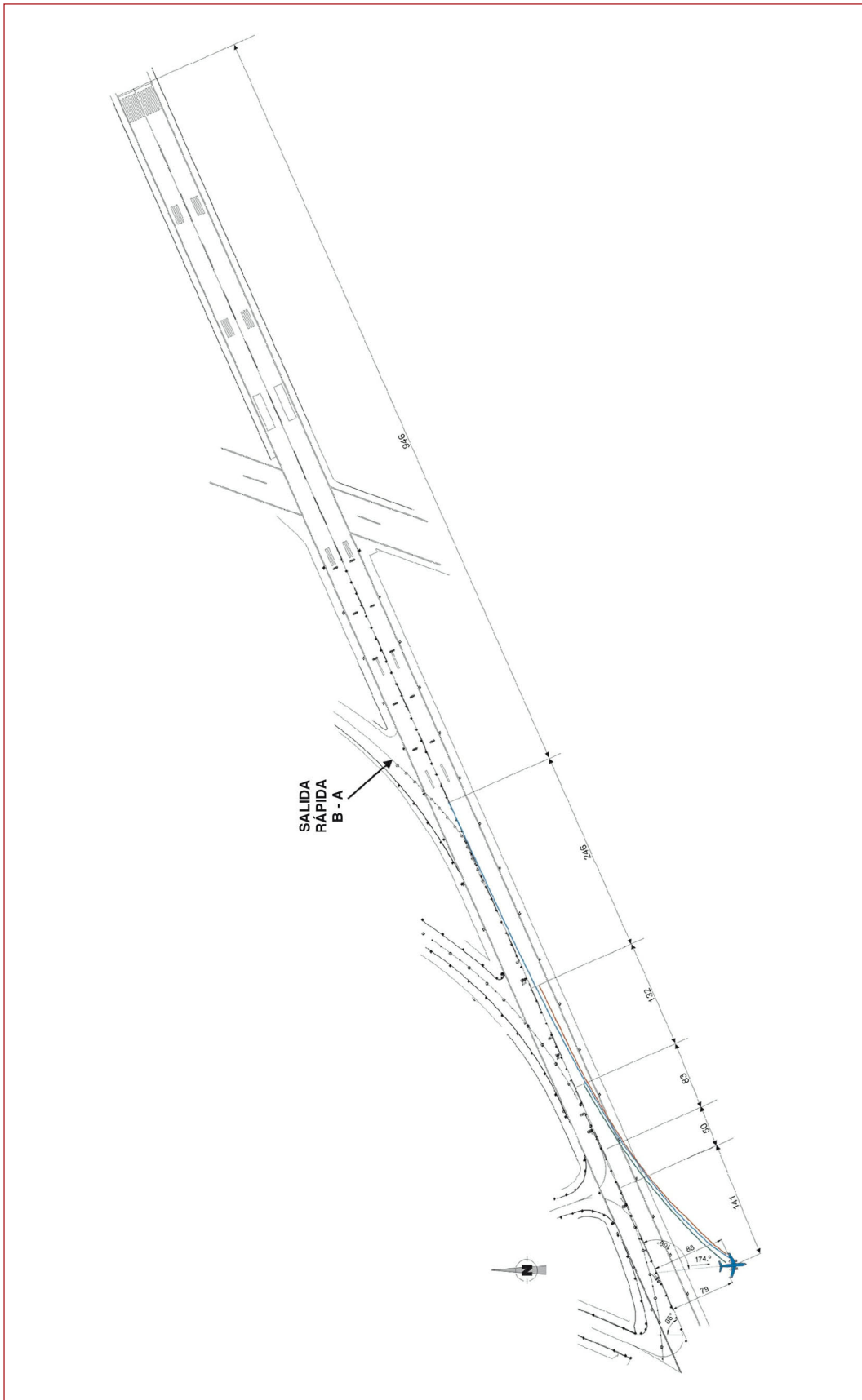
Therefore, it is considered that the new findings make it advisable that the manufacturer issues a new communication addressed to all the B737 operators to inform them about the operational consequences of the breakage of the NWS cable. The type and level of the communication should ensure that the information reaches the operational departments of the operators. Therefore, the following recommendation is issued:

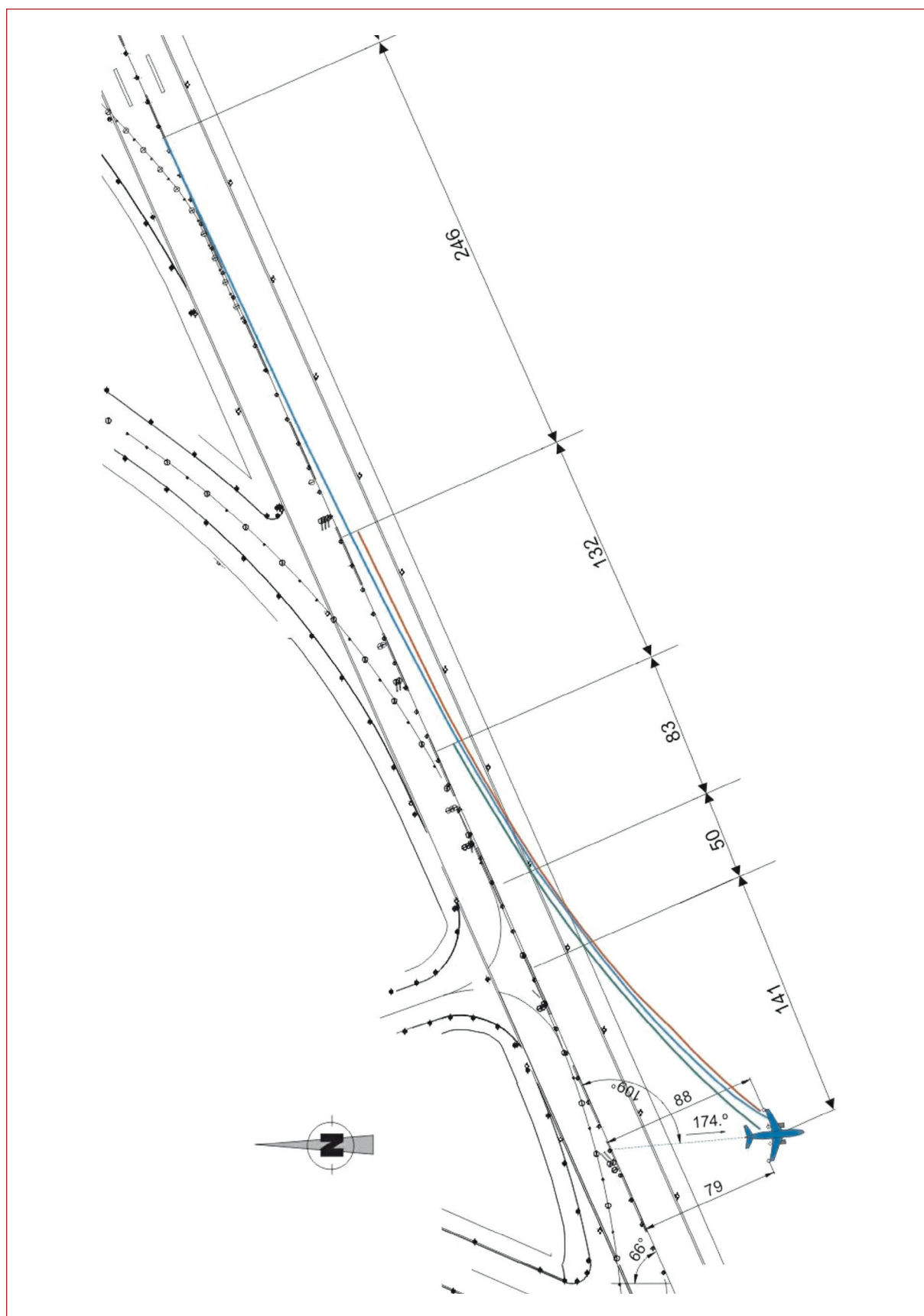
REC 26/07. It is recommended that Boeing informs all B737 operators of the technical and operational consequences of a broken NWS cable, even when it is not jammed in the deflected position.

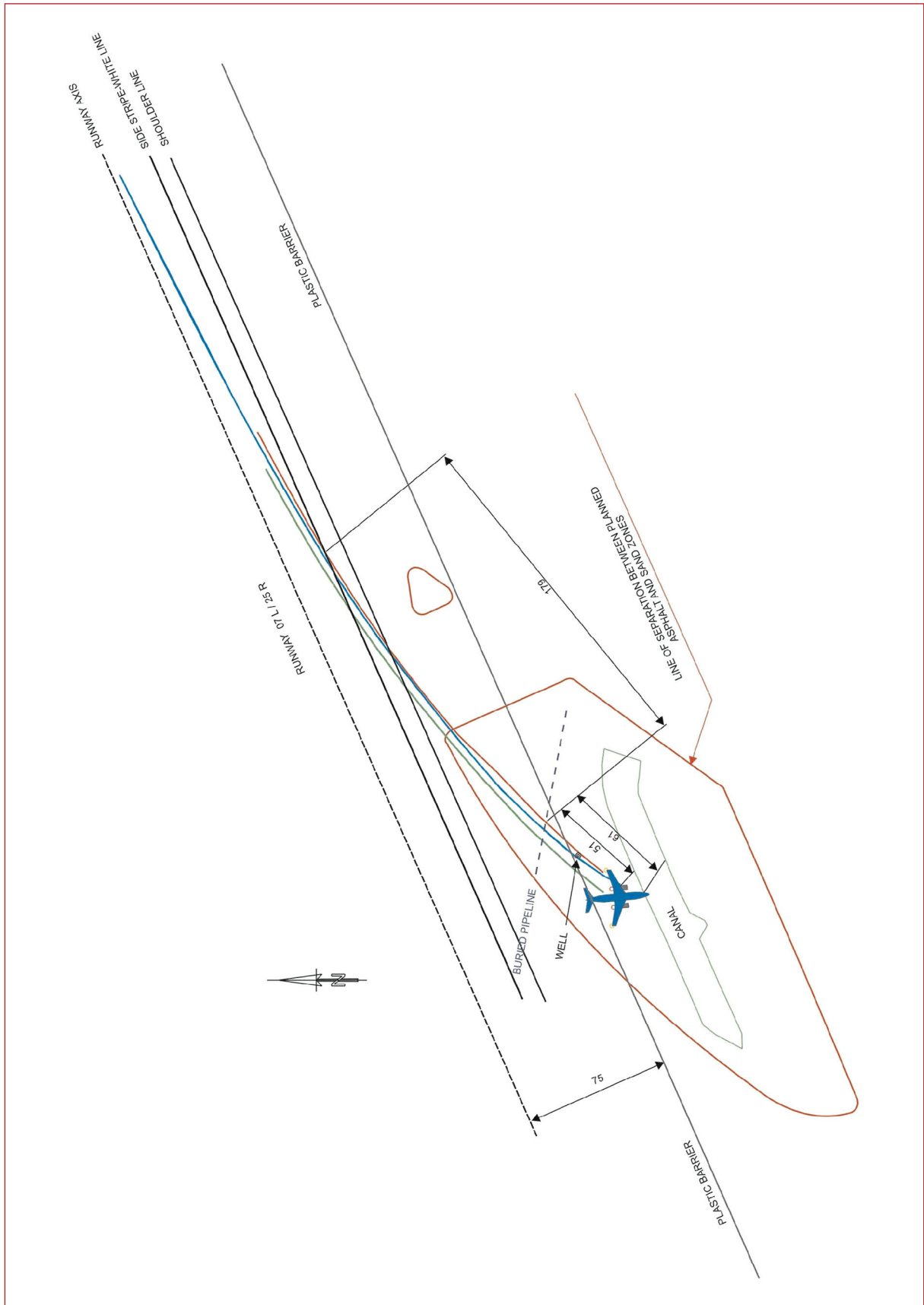
APPENDICES

APPENDIX A

Drawing of the runway marks







APPENDIX B

**Analysis of the emergency evacuation
of Boeing 737, registration PH-BTC, at
Barcelona Airport on 28 November 2004**

Abbreviations of Appendix B

AASK	Aircraft Accident Statistics and Knowledge (database)
ADT	Actual distance traveled
AMS	Amsterdam Airport
CIAIAC	Comisión de Investigación de Accidentes e Incidentes de Aviación Civil
EE	Evacuation efficiency
ISASI	International Society of Air Safety Investigators
JAR-OPS	Joint Airworthiness Requirements – Operations
JAR-26	JAR – Additional airworthiness requirements for operations
KLM	Koninklijke Luchtvaartmaatschappij -Royal Dutch Airlines
MAPSC	Maximum Approved Passenger Seating Configuration
NTSB	National Transportation Safety Board
ReqCC	Minimum required cabin crew
RvTV	Dutch Transport Safety Board
SOB	Safety on board
TSD	Theoretical shortest distance

Summary

In order to retrieve as much safety information as possible on the subject event, a questionnaire was sent to the accident passengers several weeks after the accident. The main purpose of the questionnaire was to store observational and anecdotal data.

The questionnaire, which was sent through KLM, was based on the cabin accident investigation guidelines by CIAIAC, KLM, ISASI, NTSB and the former Dutch RvTV. The original English version was translated into Spanish and Dutch.

The questionnaire consisted of questions regarding the pre-flight safety briefing, emergency exits, carry-on baggage, evacuation slides, passenger behavior, seat belts, communication, injury, post-evacuation events, and other information.

Questionnaires were sent to passenger's addresses in the following countries:

Spain (83), The Netherlands (18), Japan (14), United Kingdom (4), Rumania (3), Sweden (4), Norway (3), Paraguay (2), Canada (2), Mexico (1), Finland (1), Surinam (1), Germany (1), Costa Rica (1) and China (1).

The passengers were given the opportunity to answer by regular mail or by E-mail. Responses were received within 6 days and 124 days after the questionnaire was distributed.

With the all the responses received, the following analysis was prepared with the help of KLM cabin safety specialists.

1. ANALYSIS

1.1. Sections

For the purpose of the analysis passenger cabin sections were determined in the KLM B737-406 seating configuration, by measuring the centerline between each pair of opposite doors/emergency exits:

Section	Seat rows	Number of seats	%
Forward	Seat rows 1-6	Number of seats: 21	22%
Mid	Seat rows 7-19	Number of seats: 90	49%
Aft	Seat rows 20-26	Number of seats: 36	29%
All sections	26 seat rows	147 seats	100%

As the passenger cabin was virtually fully loaded no differentiation was made of the actual passenger seating percentage per cabin section.

Approximately 50% of all passenger seats were located in the vicinity of the mid section emergency exits, which is typical on narrow body aircraft. Source: AASK (see note 1).

1.2. Response

The first factor to be considered in the analysis of the questionnaire responses is that it is necessary to establish whether or not the data represent a fair cross-section of the passengers on board.

Average worldwide response rates to passenger questionnaires vary considerably from accident to accident. Average response rates are usually between 10 and 15 percent. Response rates over 40% are rare.

The response rate for the questionnaire of this accident was 31% (43 replies out of 140).

The questionnaire responses represented:

- 52% of the forward section (11 out of 21).
- 23% of the mid section (21 out of 90).
- 30% of the aft section (11 out of 36).

⁽¹⁾ Researchers at United Kingdom's University of Greenwich undertook an extensive data extraction and application project to derive the Aircraft Accident Statistics and Knowledge (AASK) database in order to develop airEXODUS. AirEXODUS is a computer program developed at Greenwich University that simulates passengers evacuating from an airplane.

60% of the responses came from Spain and 23% from the Netherlands. The remaining responses came from Canada (2), Rumania (1), the United Kingdom (2) and Norway (1). Of the relatively large number of residents from Japan (14) one response was received.

It was concluded that this represented a fair cross-section. Due to the spread of passengers who responded and the high percentage it was deemed feasible to make an analysis and draw conclusions using the received data. Nevertheless, some of the passengers who did not return the questionnaire may have exhibited behavior that influenced the outcome of the evacuation.

The data of 6 passengers data was retrieved through witness reports. Passenger data retrieved through reports made by the Police were used only for Evacuation Efficiency (EE) calculations and injury reports.

2. PASSENGER DEMOGRAPHICS

2.1. Age

The passenger age ranged from under 2 (infants), 4 and 5 years (children) up to 71 years. The average age was 41 years.

2.2. Height

The passenger height ranged from 153 to 198 cm (excluding infants and children). The average height was 176 cm.

2.3. Weight

The passenger weight ranged from 49 to 115 kg (excluding infants and children). The average weight was 78 kg.

2.4. Flying experience

The flying experience of the respondents ranged from reportedly «once per year» to «several» flights per year. Most considered themselves a «frequent flyer». Several specifically stated they would make at least 10 up to 40 flights and more per year.

2.5 Languages spoken

The vast majority of the respondents stated to have sufficient knowledge of one of the three languages in which the questionnaire was made: English, Dutch and Spanish.

2.6. Pre-boarding

None of the respondents was pre-boarded (passengers who need assistance during boarding and passengers with small children). There were only a few children and elderly passengers and no disabled passengers on board. None declared that their (physical) disability could have impaired egress from the aircraft during the evacuation.

2.7. Weight of hand luggage

According to passenger statements the weight of their carry-on luggage varied from 1 up to 15 kg.

2.8. Seating

The questionnaire asked about the passenger seat number. Virtually all respondents made a statement about their seat number. Some did remember their number precisely and without hesitation, others were not so sure and thus put a question mark on the cabin lay-out that was in the questionnaire. All seating data were verified with the passenger manifest.

Eight respondents stated another seat row than published on the passenger manifest, mostly with 1 or 2 seat rows difference maximum. In two cases however, the deviation was 4 seat rows. It was not determined exactly which was the actual location of these two passengers at the time of the occurrence. However, together with other statements made by them, it can be safely assumed that their actual seating position was in the near vicinity as stated.

2.9. Groups

According to passenger statements group sizes varied from 1 (which represents a passenger travelling alone) up to 9 persons in one group.

Eighteen respondents stated that they had travelled alone, twelve respondents travelled as a couple (6 couples), there were two groups of three, two groups of four, one group of five and reportedly one witnessed group of nine passengers (but none of them replied to the questionnaire).

The majority of the groups was «companion» related (not being family). In this analysis the term «companion» refers to two or more passengers that are connected by virtue of being a friend, work colleague (business associate) or other socially connected travelling associate.

Some groups were family related. Family should be treated most commonly as a unit staying and evacuating together. Statistics show that in actual evacuations where social bonds become relevant, they may cause disruption resulting in inefficient evacuation (source: AASK).

In this analysis the term «family» is not further broken down into subcategories of spouse, child etc. as the respondents did not always explicitly identify family members. It is therefore impossible to determine with certainty that all behaviour representative of family groupings has been collected.

3. PASSENGER PRE-FLIGHT SAFETY BRIEFING

3.1. Passenger attention

Despite efforts and various techniques over the years to improve passenger attention to safety briefings, a large percentage of passengers continue to ignore pre-flight safety briefings. Nevertheless, not less than 74% (32 out of 43 respondents) indicated that they had paid attention to the pre-flight safety briefing (performed by the cabin crew while standing in the aisle).

Passengers who paid attention to (parts of) the briefing were divided on the effectiveness of the briefing. Some indicated that the briefing was not particularly helpful for their evacuation; others believed it had been helpful. The latter group indicated that the briefing had made them more aware of the exit locations and the location of the emergency lighting.

Several passengers reported they had not watched the entire briefing because they had seen it before. One passenger stated being asleep during the briefing.

3.2. Briefing passengers at overwing exit rows

The KLM Boeing B737-406 has two type III overwing exit hatches on each side of the fuselage, a total of four. The type III overwing exits are «self-help exits» and these are expected to be and will primarily be opened by passengers.

Passengers seated in an exit row adjacent to the overwing exits may be called upon to assist in an evacuation. Passengers are likely to make the first attempts to open overwing hatches because cabin crew are not physically located near the overwing exits. Upon crew command or personal assessment of danger, these passengers must decide if their exit is safe to use and then open their exit hatch for use during an evacuation. These passengers must be ready to act quickly in an emergency. However, unlike the crew, these passengers receive no formal training on performing these tasks.

JAR-OPS 1.260 & 1.280 regulations require passengers to be screened for exit row seating to be «able bodied» for their task. The screening alone does not guarantee that the passenger has read the safety briefing card or understands how to open the type III overwing exit after reading the briefing card. The manner in which the exit is opened and the hatch is stowed is not intuitively obvious to passengers nor is it easily depicted graphically. Therefore, passengers were asked about the ease of opening the «self-help» overwing emergency exits.

According to safety procedures as stated in the KLM «Flight Safety Manual», cabin crew operating on a Boeing B737 must individually brief passengers on exit row tasks before take-off. Responses on the questionnaires indicate that the passengers seated in the vicinity of the four type III overwing exits had been thoroughly briefed by a cabin attendant before take-off at AMS. The language used was English.

Passengers stated that this personal briefing aided them in their understanding of the tasks that they were called upon to perform, even though there was a language problem, particularly for a few Spanish speaking passengers. Despite the communications problem the applicable passengers were positive and they stated that the briefing had been very helpful and was highly appreciated. Some passengers commented it had been the very first time ever that they were briefed on any emergency exit operation.

Five passengers declared to have opened an overwing exit during the emergency evacuation. O1R was opened by two passengers. One passenger reported that a female passenger had been unable to open the exit hatch and eventually allowed another passenger to open it. One passenger reported that he had to apply «three firm pulls» to open the hatch. The other overwing hatches were opened easily and without difficulty.

3.3. Safety On Board (SOB) card

The majority of the respondents stated that they had not read the SOB card on this flight because they had read it (many times) before on other flights.

Only 23% (10 out of 43) of the respondents declared that they indeed did pay (some) attention to the SOB card. Some indicated that the SOB had been helpful for their evacuation. The primary benefit of the card was for identifying emergency exit locations.

4. THE OCCURRENCE

4.1. Brace

As the occurrence was completely unexpected none of the passengers assumed the «brace» position as drawn on the Safety On Board card. Most grabbed their seat arm

rests or the seat back in front, while trying to protect their heads. Some passengers reported that their heads were slammed against the side wall panels and tray table during the impact sequence.

4.2. Seat belts

All respondents declared that their seat belt functioned as designed and that they didn't have any problems in releasing their seat belt.

However, a 69 year male passenger reportedly seated at seat 9B (7A on the passenger manifest) declared that his seat belt unbuckled even before the aircraft came to a full stop. He ended up on the cabin floor, but was not injured. This passenger had no plausible explanation for this occurrence, but he suggested he himself may have opened the belt.

4.3. Smoke and dust

Many respondents specifically made comments on smoke, fumes, dust or sand clouds they saw during the occurrence inside the passenger cabin. Reportedly these witnesses were seated throughout the entire passenger cabin. Some passengers noticed a «bad smell» of electrical origin. Initially the smoke and fumes phenomenon caused some form of panic. During the investigation the source of these «clouds» remained undetermined.

4.4. Cabin damage

Several passengers reported that immediately after the aircraft came to a complete stop it was not completely dark in the cabin. However, others stated it was completely dark. Several stated that they saw (parts of) emergency lighting. Many of them saw overhead compartments opening and luggage falling out.

Panels and passenger service units were open and at some locations oxygen masks were hanging down. During the evacuation one passenger became entangled in tubes from hanging oxygen masks and had to be freed by another passenger.

4.5. The role of cabin crew

The difference between a successful and an unsuccessful evacuation can be a matter of minutes or seconds. Therefore, clear and precise procedures must be in place and readily available to assist the crew. The speed at which passengers evacuate is therefore highly dependent on the actions of the cabin attendants. Once the decision to evacuate the aircraft is made, the cabin crew has to decide which exits to use.

Upon hearing the captain's command(s) to evacuate, the cabin crew members shouted the standard commands to evacuate the aircraft and they began their evacuation procedures.

4.6. Initiation of the evacuation

Several passengers stated that they heard a command similar to «EVACUATE, EVACUATE» over the Passenger Address System. This command was announced by the captain. Cabin attendants then began to shout the command «EMERGENCY–OPEN SEAT BELT-EVACUATE».

Speed is the primary reason for using shouted commands. By some respondents this shouting was experienced as a sign of stress or «panic» amongst the cabin crew.

None of the respondents could remember the exact wording of the English evacuation command as shouted by the cabin crew. Several Spanish speaking passengers commented that they didn't understand the commands shouted by the cabin crew, both inside and outside the aircraft.

Several passengers seated in the vicinity of the overwing emergency exits stated that they did not hear any command from the captain at all. Throughout the evacuation process, various passengers located in the mid-cabin were unable to hear any subsequent instructions given by the cabin crew.

The success of the evacuation was attributed in part to the fact that almost all the passengers remained very calm and disciplined. Passengers stated that the situation could have been very different if there had been smoke and/or fire.

4.7. Retrieval of Carry-on Luggage

Passengers' efforts to evacuate an aircraft with their carry-on baggage continue to pose a problem and are a serious risk to a successful evacuation of an airplane. Passengers exiting with carry-on baggage were frequently mentioned as obstructing the evacuation. It is considered that this problem should be addressed and ways to minimize the problems associated with carry-on luggage during evacuations should be developed.

Air carriers use various methods to instruct passengers not to take personal belongings during an evacuation. One method is the safety-briefing card. The «Safety On Board» (SOB) card used in the accident flight did not indicate that carry-on luggage should not be taken during an evacuation. The only pictogram used on the applicable SOB-card was a shoe in the centre of a slashed circle, indicating to take «high healed shoes» off before jumping into an inflatable slide.

Another method is flight attendants' commanding to leave everything during the evacuation. All cabin attendants indicated that they commanded passengers to leave everything behind. Non-standard commands were used like «NO LUGGAGE, LEAVE EVERYTHING». The KLM procedures did not provide any such command. Despite the efforts made by the cabin crew, a large number of passengers took their belongings. Passengers continued, in an unhurried manner, to retrieve their personal belongings and prepare to leave the airplane.

All cabin attendants reported that their attempts were frustrated by passengers' insistence on retrieving their carry-on luggage before evacuating.

Eleven respondents stated having carried at least one piece of luggage during the evacuation. Twentyfive respondents stated they did not carry any. Eleven respondents did not give information about this matter.

The primary reasons that passengers stated for retrieving their bags were documentation, passports, tickets, money, wallet or credit cards. Other reasons included job items, keys and medicines. Some passengers stated that taking their hand luggage had caused much less inconvenience later when in the Terminal building at Barcelona, because they had their documentation with them, such as passports etc.

Although not everyone attempts to retrieve and take carry-on baggage during an evacuation, everyone in the airplane could potentially be affected by these attempts. Several passengers without luggage reported waiting behind one male passenger trying to manoeuvre a large garment bag through the aisle.

None of the passengers or flight attendants reported arguments between passengers and cabin attendants regarding luggage.

4.8. Crew seating

There was a forward facing double occupancy flight attendant jump seat at the forward entry door (1L) exit, one aft facing double occupancy flight attendant jump seat at the aft entry door (2L) and one single aft facing occupancy flight attendant jump seat at the aft service door (2R).

4.9. Miscellaneous

During the runway excursion, two passengers (spouses) seated on seat row 25 felt that they were being pushed forward in their seats by the seatbacks. These passengers also observed sparks of undetermined origin.

5. ANALYSIS OF EXIT USAGE

Of 50 passengers data was retrieved about their emergency exit usage:

Number	Emergency exit	«X» Number of known evacuees	«X»/50 passengers × 100%
1L	Forward Entry Door	15	30%
2L	Aft Entry door	18	36%
1R	Forward Service door	nil	0%
2R	Aft Service door	nil	0%
O1L	Forward Overwing left	8	16%
O2L	Aft Overwing left	nil	0%
O1R	Forward Overwing right	6	12%
O2R	Aft Overwing right	3	6%

6. EVACUATION EFFICIENCY

There are many ways in which the evacuation efficiency can be defined, for example: time required to evacuate, number of injuries/fatalities incurred during evacuation, the average distance traveled by passengers, exit flow rates achieved, passenger distribution between available exits, etc.

In the following analysis the efficiency of the evacuation is determined by the average distance traveled by passengers. It is assumed that the shorter the average distance traveled by passengers, the more efficient the evacuation (source: AASK).

6.1. Seat rows

Distance calculations were based on the number of seat rows between the passenger seat location and the exit used. All distances were calculated in terms of seat rows for each passenger and averaged over the number of passengers involved. The number of seat rows was calculated over the center line of the cabin aisle towards the nearest emergency exit, irrespective of cabin furnishing like galleys, lavatories, closets or coat-rooms in between.

No difference was made between aisle seated and non-aisle seated passengers. Statistics show that being seated on an aisle set provides only a marginally higher chance of survival than not sitting on the aisle (source: AASK).

Neither of the two right hand floor level exits was used for evacuation. No differentiation was made between left hand side and right hand side emergency exits, as the Boeing 737-406 is a single aisle («narrow body») aircraft.

6.2. ADT/TSD

The ratio between the Actual Distance Traveled (ADT) and the Theoretical Shortest Distance (TSD) is a measure of the additional travel distance incurred by the passengers due to sub-optimal exit choice. Here we simply define the Evacuation Efficiency (EE) as $TSD/ADT \times 100\%$. An EE of 100% indicates that a passenger made use of the nearest viable exit.

To be truly representative, the distance calculations used to determine ADT/TSD must be based on a sample involving a significant number of passengers on board, which was actually the case as during this flight 139 seats of the 147 seating configuration were occupied.

Questionnaire statements from passengers also provided insight into how easily passengers were able to access exits and what interior furnishings impeded their access.

For the calculation of the EE the seating as declared by the respondents was used, not the passenger manifest.

6.3. TSD

The Theoretical Shortest Distance is calculated assuming that all passengers use their nearest available exit.

The TSD refers to distance from the passenger's starting location (seat row) to the nearest *available viable* exit, irrespective left or right hand side and not affected by major damage, slide failure, fire, smoke, debris, etc.

For the applicable cabin configuration, the passengers were located on average 6.25 seat rows from their nearest emergency exit, irrespective whether this exit was viable.

6.4. ADT

The Actual Distance Traveled (ADT) represents the average actual distance travelled by each passenger.

The number of exits available to the passengers will normally have an impact on the travel distance, which is dependent on the nature of the aircraft configuration and the

accident details. Non-influential factors such as the presence of smoke and fire have not been factored in this analysis.

6.5. EE

The analysis learns that an overwhelming 86% (42 out of 49 reports) shows an EE of 100%. The average EE for the entire passenger cabin was: 96%.

EE per section:

- Forward section: 10 out of 11: 90%
- Mid section: 16 out of 21: 76%
- Aft section: 14 out of 14: 100%

The lowest EE was 11% for a male passenger who travelled 9 seat rows while his seat was just 1 row in front of the overwing. From his statements it was concluded that he must have been unaware of that nearby overwing emergency exit.

The results of this investigation confirm the observation done in AASK; the majority of the survivors making use of the nearest available exit or have a good reason for not using their nearest exit. However, it should be realised that an EE-score of 100% does not necessarily mean that the passenger chose for the fastest evacuation possible.

Passengers in the vicinity of the overwing exits stood in line to use these exits. Some stated that they looked around to see if an alternative exit was available. 24% of them deliberately chose to go for another viable exit. That is why these passengers got an EE score of less than 100%.

7. EVACUATION TESTIMONIES

7.1. Passenger observations

Most passengers reported that during the evacuation there was no panic. Some respondents called the evacuation «civilized». Outside the aircraft a number of passengers exiting from the forward entry door slid into the canal.

Several passengers seated in the vicinity of the overwing emergency exits reported having received assistance from a fellow passenger, a male of approximately 50 years of age. This passenger had been very helpful in calming them down down and in assisting in the evacuation, both inside and outside the aircraft. This undetermined person (reportedly a pilot from a Spanish commercial airline) used both Spanish and English instructions.

Passengers seated in the mid-section of the passenger cabin thought it strange that they were not helped by crew at the overwing exits. Their perception and feeling was that they were left abandoned. This is explained by the fact that no cabin crew is seated near the overwing emergency exits.

Passenger 11A opened the forward left hand overwing emergency exit and then he saw emergency escape slides inflating. Passenger 12F opened the aft right hand overwing emergency exit, evacuated and as she stood on the wing she saw the emergency escape slides inflating.

Most passenger clustered in groups at 30 to 100 meters distance from the aircraft. Passengers were seen on the runway and were called back by fellow passengers. Several passengers were aware of the danger of being run over by rescue vehicles or landing aircraft. Some passengers were smoking cigarettes or tried to but were stopped by fellow passengers, while others took pictures or video. Many respondents realised danger still existed after the evacuation. The fire fighting crew shouted to the passengers to move away, quote: «...as this thing could explode...» unquote.

Once outside several passengers became emotional and were in great disbelief, confused and amazed. Several were very cold because they had become wet in the ditch. Some were in panic, basically because they didn't understand the English verbal instructions given by the crew. Fellow passengers started to translate for them. Others expressed their luck after surviving the accident.

Passenger estimation about the duration of the evacuation varied. More than half thought the evacuation took less than 1 minute, many others thought it took between 1 and 2 minutes.

The highest estimate was «less than 5 minutes».

7.2. Clothing

Passenger 3F commented on the suitability of clothing and footwear for the evacuation. As she slid into the ditch her coat got soaked with water, which hampered her attempts to get out of the ditch. Virtually all other respondents commented that their clothing and footwear had been suitable.

7.3. Competitive behaviour

The passengers were surveyed on competitive behaviour they may have exhibited or observed during the evacuation. Experience shows that the severity of an event is not necessarily indicative of unco-operative or competitive behaviour. Competitive behav-

four passengers could be defined as pushing, climbing seats and disputing among passengers.

None reported that they had climbed over seats or had seen others climbing over seat backs. None reported seeing passengers pushing (or being pushed). None reported seeing passengers in serious dispute with other passengers (except for the fact that one passenger took too much time to get a large bag from the overhead compartment).

7.4. Injuries and how they were sustained

Five females and four males reported on the injuries they sustained during their evacuations. Their injuries varied. Five of them were shortly hospitalized for medical examination and treatment (passengers 4C, 11B, 12F, 18B and 26D). One of these passengers suffered a whiplash. She evacuated through an overwing exit and fell on her back when jumping off the wing.

A former cabin attendant declared she had deliberately taken off her shoes before jumping into the slide. As a result she sustained small cuts on her toes. Reportedly there must have been at least three more passengers with bleeding cuts on their bare feet.

Some passengers declared to have suffered from muscular tension and bruises sustained during impact. No attempt was made to confirm each passenger's self-assessment stated in the questionnaire. There appeared to be no relationship between gender or age and the injuries incurred.

7.5. Slide malfunction

The inflatable slide at 1R (forward service door) failed to inflate correctly. No passenger attempted to use this exit. The relatively high incidence of problems associated with one evacuation slide is cause for concern and is under investigation.

7.6. Rescue

The majority of the respondents thought that rescue came «within 5 minutes». Several stated that help arrived only after 10 to 15 minutes.

7.7. Miscellaneous

The passenger questionnaire did not state a question whether passengers had been involved in a prior evacuation. No respondent mentioned any similar experience, except for both former cabin attendants during their flight safety training.

The first passenger to respond by E-mail had attached two digital pictures made shortly after he had evacuated. One picture was very useful for the technical investigation of the accident, because it showed parts of the overwing emergency lighting illuminated.

A few passengers commented on their concerns about missing their connecting flight because the Police did not allowed to leave the arrival hall or because of the fact that they simply didn't have their documentation or luggage at hand.

8. CABIN CREW

8.1. Minimum Required Cabin Crew

The «minimum Required Cabin Crew» (ReqCC) is established according to JAR-OPS 1.990 (b)(2). For this regulation the Boeing B737-Series «Type Certificate Data Sheet» number A16WE is applicable.

With an MAPSC (see note 2) of 147 passenger seats the ReqCC is 4 qualified flight attendants. At the time of the accident 4 flight qualified flight attendants were on board, which complies with the regulations.

8.2. Cabin Crew Performance

The general feeling of the majority of the respondents was that the crew was well trained and competent for their tasks. Reportedly their actions had been calm, collected and professional.

A few passengers commented that the crew had been nervous, some described it as «in panic». Particularly the passengers in the mid section complained they hadn't seen any crewmember at all during the evacuation.

8.3. Cabin Crew Staffing Levels

The ratio of crew-to-passengers required for the safe operation is a complex issue involving many factors.

⁽²⁾ JAR 26.2 «Maximum Approved Passenger Seating Configuration (MAPSC)»: The maximum passenger seating capacity of an individual airplane, excluding pilot seats or flight deck seats and cabin crew seats as applicable, used by the operator, approved by the Authority and specified in the Operations Manual.

From a safety viewpoint it may be desirable to maintain a passenger-crew ratio that is as low as practical as in the event of a serious accident. The performance and number of cabin crewmembers may significantly influence evacuation rates and passenger behavior.

It is assumed that the crew plays a vital role in managing the evacuation of passengers. This role includes guiding passengers to their exits as well as speeding their passage through the exit. The more (well-trained and active) crew is available to direct the passengers, the more likely passengers are of utilizing their optimal exit.

The AASK database shows that, particularly on small narrow body aircraft, if the relationship between EE and cabin crew numbers can be generalized, the loss of even a single cabin crewmember may have serious implications for passenger safety⁽³⁾. When there is a small number of crew available to control the evacuation, passengers tend not to make use of their optimal exits, but tend to travel significantly further than necessary in order to evacuate.

During their interviews the cabin crewmembers stated that they were bolstered in their confidence and ability to cope specifically because they were not alone. If a single CA must redirect passengers from an unusable exit and then pass passengers to open another exit, the question arises if this is possible.

Finally, also the presence of smoke or fire may play a role in passenger exit selection. This would have been particularly relevant if extra time was spent in egress, which could have compromised the survival chances of the passengers. This was not the case in this accident.

9. PASSENGER TO CABIN CREW RATIO

9.1. The theoretical maximum passenger to crew ratio

The total number of cabin attendants scheduled for this flight was 4.

For an MAPSC of 147 passenger seats on this aircraft and the 4 cabin attendants scheduled, the theoretical maximum passenger-to-crew ratio was: 36.75 to 1.

Around the world the accepted crewing level varies from around 36:1 to 50:1 passengers per cabin crew member. The number of additional cabin attendants scheduled depends on the flight destination, the flight duration and the service schedule on board.

⁽³⁾ AASK suggests that for wide body aircraft perhaps the efficiency ratio as defined above may be inappropriate! Based on the definition of evacuation efficiency, preliminary analysis suggests that for large wide body aircraft, higher numbers of operational crew may lead to declines in evacuation efficiency. This is thought to be due to more instances of passenger redirection and exit bypass, resulting in passengers traveling further than the theoretical minimum distance.

9.2. The actual passenger to cabin crew ratio

Operational cabin crew is defined as those crew members who were uninjured or who sustained only minor injuries and were therefore able to actually take an active part in managing the evacuation.

During the evacuation all 4 cabin attendants remained operational. Hence, for the 140 passengers on board at the time of the accident and the 4 operational cabin attendants, the actual passenger-to-crew ratio was: 35 to 1.