DATA SUMMARY

LOCATION

Date and time	**Thursday, 20 January 2005; 03:26 h UTC**
Site	**Atlantic Ocean, en route from Santo Domingo (SDQ) to Madrid (MAD); coord. 29.6°N 50.7°W**

AIRCRAFT

Registration	**EC-HPU**
Type and model	**BOEING B767-300**
Operator	**Air Europa**

Engines

Type and model	**GENERAL ELECTRIC CF6-80C2**
Number	**2**

Crew

	Pilot in command	Copilot
Age	**48 years**	**38 years**
Licence	**ATPL**	**ATPL**
Total flight hours	**13,100 h**	**4,800 h**
Flight hours on the type	**2,100 h**	**2,500 h**

INJURIES

	Fatal	Serious	Minor/None
Crew		**1**	**10**
Passengers			**269**
Third persons			

DAMAGE

Aircraft	**Minor**
Third parties	**None**

FLIGHT DATA

Operation	**Comm. air transport – Scheduled international passenger**
Phase of flight	**En-route – Cruise**

REPORT

Date of approval	**30 May 2007**

1. FACTUAL INFORMATION

1.1. History of the flight

On 20 January 2005, Boeing 767-300 EC-HPU, with 11 crew members and 269 passengers on board, took off from Santo Domingo Airport (Dominican Republic) at 00:53[1] on a scheduled passenger flight to Madrid Airport (Spain). The flight crew was adequately rested for the flight and reported having reviewed the relevant meteorological information before takeoff. The forecast showed the possibility of a cold front line between 25N045W and 50N40W, and also some embedded cumulonimbus clouds, in an area to be crossed later by the aircraft while en route.

The flight proceeded normally. After two and a half hours of flight, the dinner service had finished and the cabin crew was clearing the meal trays. The aircraft was flying at Mach 0.81, FL 330 on a heading of 071°. As it went through 29°N 50°W, the area for which storms were forecast, it started to accelerate to 300 KCAS, Mach 0.84 and 581 kt ground speed. The captain was at the controls at that time. The aircraft was under the control of the central autopilot, with auto thrust engaged and 91.6% of N1 on both engines.

Even under the nighttime conditions, the flight crew could see the moon reflected on the cloud tops and flashes of lightning, so the captain tried to avoid that area. According to FDR data, at 03:26:12 the aircraft was in a turn with a roll gradually increasing from 6° to 16°.

Upon noticing light turbulence, the "fasten seat belt" signs were turned on at 03:26:13. Seven seconds later, the aircraft entered an area of severe turbulence. At that time the cabin attendants were returning to the galley area and one of them was trying to reach the intercom to inform the passengers of the turbulence.

At 03:26:20, while the aircraft continued in a turn with 16° of roll to the right, the Mach number reached 0.868 and then 0.874. Four overspeed warning readings were recorded on the FDR.

At 03:26:23, coinciding with the fourth overspeed warning reading, the upward vertical acceleration increased from 1 to 2 g in a second, and remained close to 2 g for a further two and a half seconds. The warning disappeared the following second, and appeared again for a single and last instance, as the maximum vertical acceleration of 2.081 g was reached. No other overspeed warning was recorded for the duration of the event.

[1] All the times are UTC times unless otherwise noted.

The aircraft climbed at a high rate, with an increasing pitch angle and decreasing calibrated airspeed. The vertical acceleration started to decrease and reached a minimum of 0.318 g at 03:26:36 (with the aircraft at 34,800 ft) and then went back to 1 g in less than a second.

As a result of these significant variations in vertical acceleration, several flight attendants who were standing were thrown against the ceiling and then against the floor of the cabin. A flight attendant (located in the front part of the cabin) suffered a fractured tibia and fibula. Three other cabin crew members suffered injuries due to heavy impacts with the floor, ceiling, seats or trolleys. A passenger standing in the restroom also suffered a foot injury.

The aircraft continued climbing up to 35,800 ft while still enduring turbulence that made acceleration oscillate between 1 and 0.322 g until 03:26:58. The calibrated airspeed and Mach number varied considerably.

The turbulence persisted, with acceleration increases of up to 1.2 g lasting several seconds. At 03:27:11, the autopilot was disconnected. The aircraft started a descent and, upon reaching 34,200 ft, the autopilot was engaged again. The auto thrust remained engaged throughout the whole event.

The aircraft reached 33,000 ft and remained at that altitude for 5 minutes before climbing to 33,300 ft and, after several minutes, returning to the original flight level FL330, still in light turbulence. At around 03:39 they informed the New York Air Route Traffic Control Center (ARTCC) of the severe turbulence, relaying that they had climbed to FL350 and returned back to FL330 and reported a wind of 74 kt from 258°.

They requested a change in flight level and a 10 NM deviation to the right of the planned course. The flight level change was denied (UHDT: "unable higher due traffic") by the ARTCC at 03:49 because of opposing traffic in the area. The 10 NM deviation was approved.

At 03:53 the aircraft informed it was "BACK ON COURSE NOW" (that is, on its previous course) at 33000 ft. There was another communication at 04:36 in which the flight crew informed they were at 33ºN 040ºW with –49° of static air temperature and wind at 32 kt from 311°.

Those injured were assisted on board by a doctor who was travelling as a passenger. Since they had already covered almost half their route, they decided to continue on to Madrid, where they landed at 08:57 without further incident.

Maintenance personnel inspected the aircraft due to the turbulence and overspeed conditions encountered. No discrepancies were found.

1.2. Personnel information

1.2.1. *Pilot in command*

Gender, age:	Male, 49
Nationality:	Spanish
License:	ATPL, valid until 23 Apr 2007
Total flight hours:	13,100 h
Flight hours on type:	2,100 h (as pilot in command)
Flight hours last 28 days:	60

1.2.2. *First officer*

Gender, age:	Male, 39
Nationality:	Spanish
License:	ATPL, valid until 23 Mar 2007
Total flight hours:	4,800 h
Flight hours on type:	2,500 h (as co-pilot)
Flight hours last 28 days:	77

1.3. Flight recorders

The aircraft was equipped with a cockpit voice recorder (CVR), but the information relevant to the accident was recorded over due to the duration of the flight after the event. The digital flight data recorder (DFDR) was downloaded and a copy of the relevant data was available for the investigation.

According to these data, the event started at 03:26:13 when the fasten seat belts signs were turned on after light turbulence was noted and severe turbulence anticipated. The aircraft was at those moments at 29.6°N 50.7°W, FL 330, 300 KCAS and 581 kt of ground speed, with the autopilot and auto throttle engaged. The angle of attack indicator showed –11.3.

A sequence of the most relevant events follows (see evolution in Figure 1):

Tiempo (hh:mm:ss)	Time (seconds after 03:26:13 h)	Comment	Altitude (ft)	Airspeed (KCAS)	Pitch angle (degrees) and cap control column position (degrees)	Vertical acceleration (g)
3:26:13	0	Fasten seat belt signs on	33,011	301	1.4 (0.5)	0.998
3:26:20	7	Overspeed warning sounds for 3 sec	32,955	312 (Mach 0.874 reached in the following second)	0.9 (0.4)	1.092
3:26:25	12	Highest value of vertical acceleration	33,156	309	8.6 (–3)	2.081
3:26:36	23	Lowest value of vertical acceleration	34,823	241	14.1 (–4.4)	0.318
3:26:37,5	24.5	Acceleration goes back to 1.14 g	34,930	235	17.8 (2.3)	1.14
3:26:49	36	Maximum altitude reached	35,865	224	3 (1.8)	0.588
3:27:11	58	Autopilot disconnected	34,936	247	2.8 (–0.7)	1.153
3:28:15	122	Autopilot connected again	34,235	271	3.2 (3.2)	0.922
3:35:00	527	Turbulence subsides	33,023	287	1.9 (0.4)	0.961

Additionally, the aircraft was probably swept up in a strong updraft which led to the high vertical acceleration. The climb rate increased and the aircraft climbed 2,800 ft in 36 s (4,600 ft/min average). The pitch angle increased and leveled out for a period of time before dropping sharply, which resulted in the minimum vertical acceleration value. A new ascent immediately followed which took the pitch angle to a maximum of 19.2° as a local positive acceleration peak of 1.14 g was reached.

The ground speed varied between 507 kt at 03:26:46 and 593 kt at 03:28:46. The aircraft experienced a noticeable variation in the tailwind when the turbulence started (see Figure 2).

The auto thrust was engaged throughout the event. When the turbulence started, the autopilot moved the controls normally to try to counteract its effects, though it could not prevent the peaks in acceleration and overspeed.

The rudder deflexion varied between 2.29° (03:26:28) and –2.02° (03:26:36).

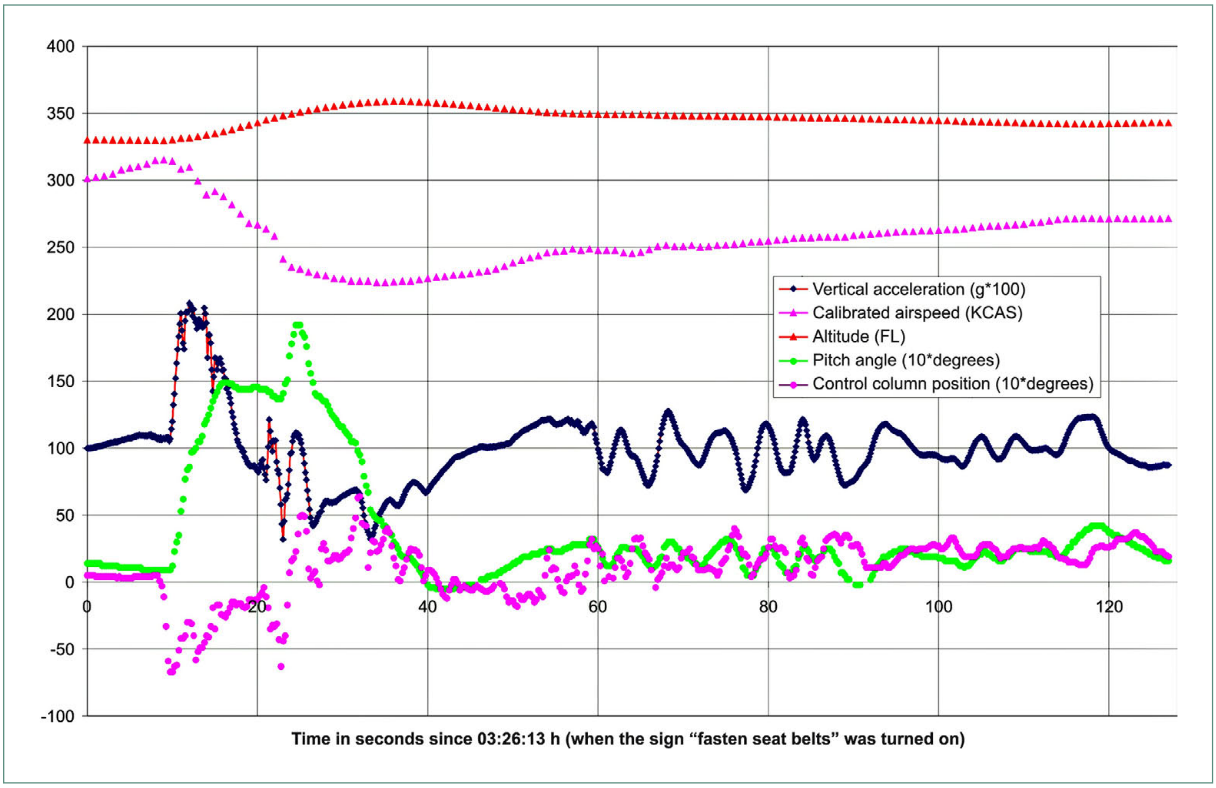

Figure 1.

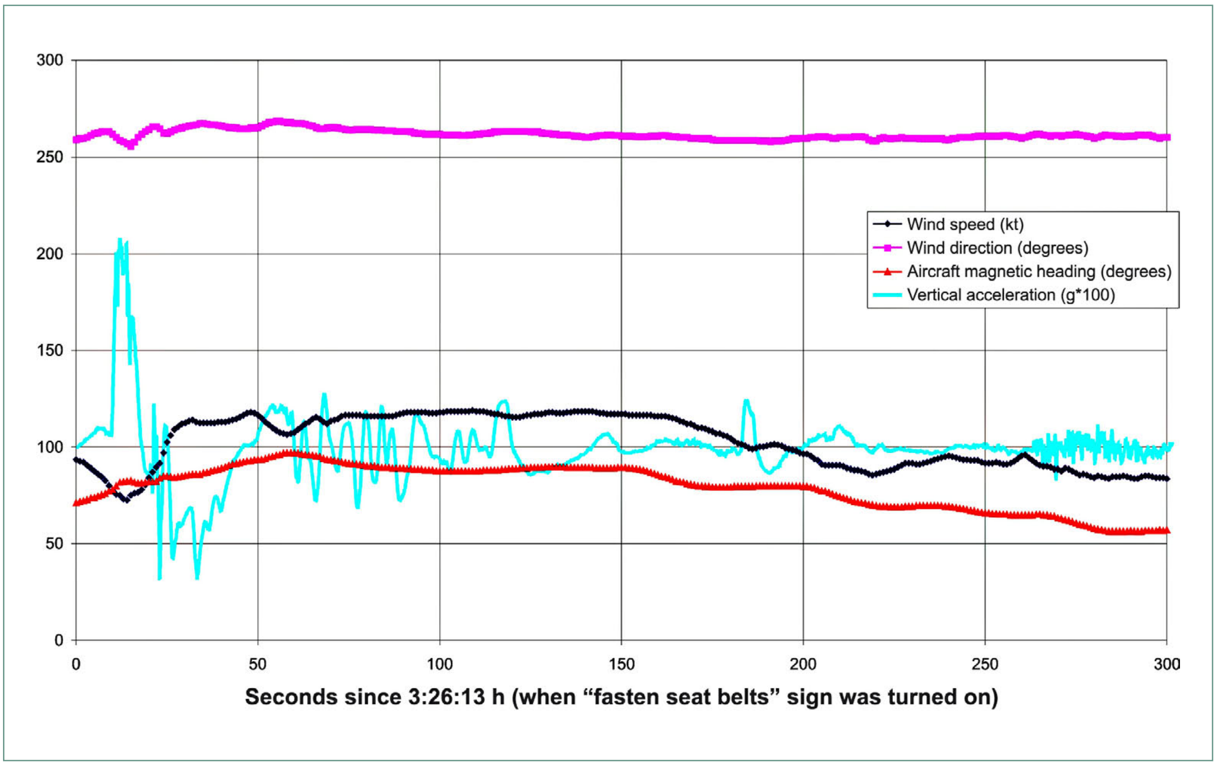

Figure 2.

1.4. Meteorological information

The captain and first officer of the aircraft had received relevant weather information before departing. The forecast chart from the World Area Forecast Centre in London, valid at 00:00 of that day (see Figure 3, with the scheduled route of the aircraft highlighted), showed a front with isolated embedded cumulonimbus clouds from below FL250 up to FL350 in the area of 50° W and latitude 30° N. There was also a west-east jet stream nearby at FL390 with forecast wind speeds of around 100 kt. This jet coincided with a break in the tropopause (from subtropical tropopause at FL500 to polar tropopause at FL350).

Additionally, clear air turbulence (CAT) was forecast for the area between FL330 and FL440 (see Area 5 in the chart, and altitudes in the box "CAT AREAS", lower part of Figure 3).

The forecast from WAFC Washington also included the jet stream with a cold front in the area marked with an arrow, with embedded and isolated cumulonimbus clouds from FL330 to below FL 250.

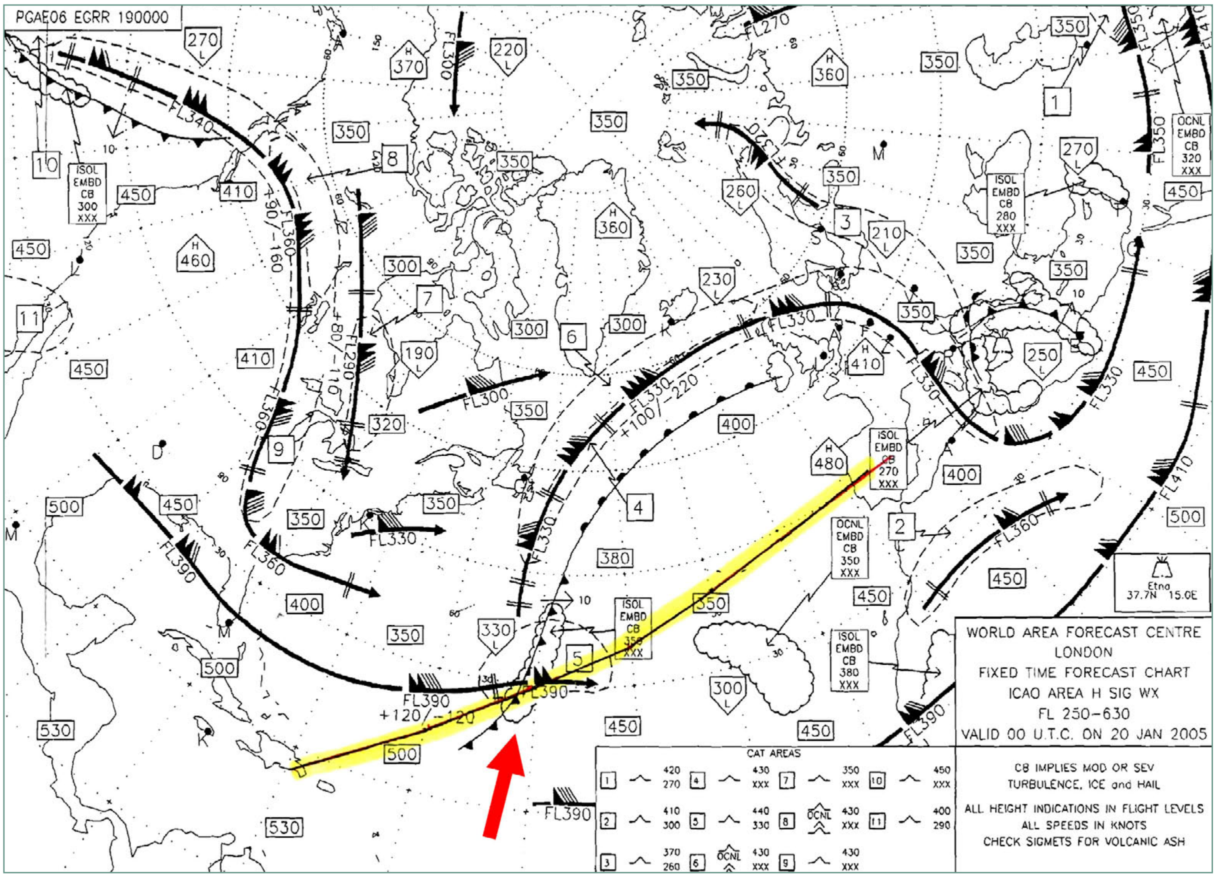

Figure 3. Chart from the London WAFC, with the planned aircraft route highlighted in yellow. An arrow points to the approximate area wher the accident happened

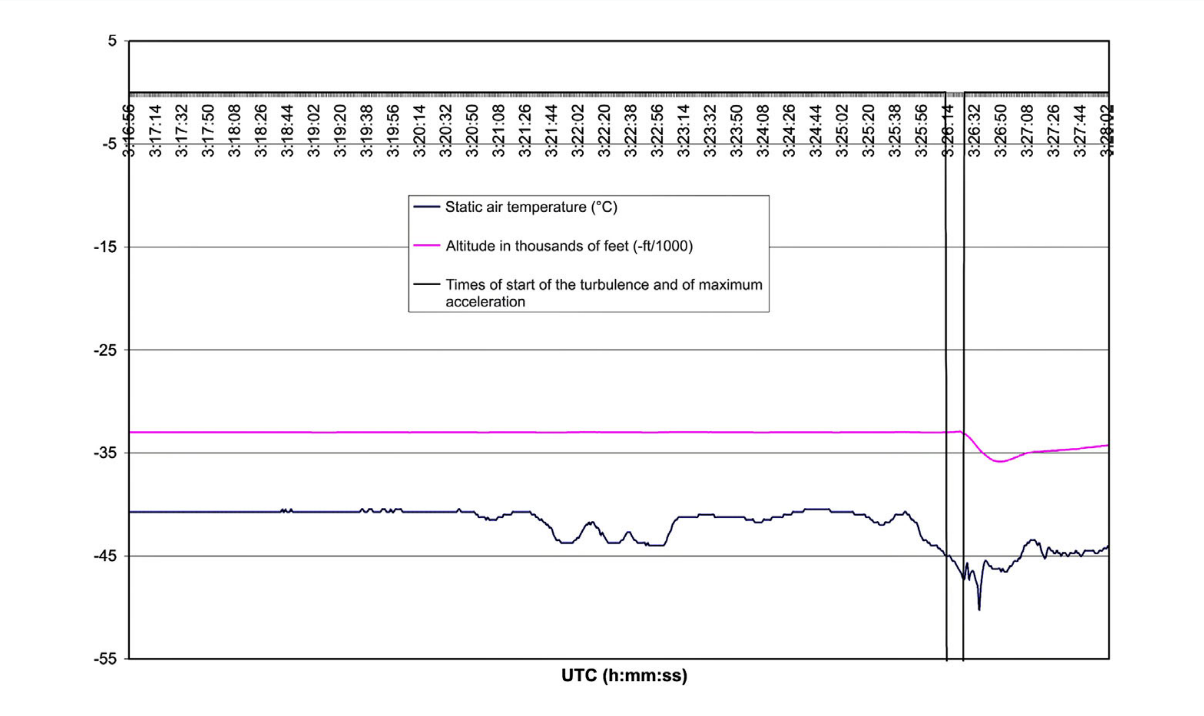

Figure 4. FDR data showing the temperature drop as the aircraft approached the turbulence zone. At 03:26:25 the maximum vertical acceleration was reached and the aircraft climbed abruptly (*Note:* the altitude has a negative sign in the graph to facilitate comparison with the static air temperature)

The FDR data show that the static air temperature (SAT) remained approximately constant until 03:21:40, when it started to oscillate downward. This could have signaled that the aircraft was approaching the jet stream and possible clear air turbulence.

This fact, along with the constant increase in wind that, for a given value…..the time is progressively reduced, given that the width between isotachs slowly decreases when crossing from south to north.

The proximity to the stream takes place when the observed wind reaches its maximum intensity. This value equals the stream's if crossed as the same altitude.

Crossings above and below the jet stream will result in wind speeds below that of the stream.

The height indications shown on the maps provide important supplementary information in that they allow for the interpolation of intermediate values of wind intensity.

1.5. Operational procedures

1.5.1. *Aircraft information*

The Boeing 767 Operations Manual, "Supplementary procedures" section, "Adverse Weather", states that the autopilot may remain engaged while flying in moderate turbulence unless manual control is required to effect speed, attitude or altitude changes. The turbulence penetration speed is 290 kt/0.78 Mach. The subsection on "Severe Turbulence" states that such turbulence is to be avoided whenever possible. If unavoidable, it recommends increasing the margin to buffet by descending some 4000 ft below the optimum altitude. Auto thrust should be disengaged when in severe turbulence.

Boeing's Flight Crew Training Manual (FCTM), in its section on Turbulent Air Penetration, gives general indications concerning manual operation under turbulent conditions, including the recommendation of using the artificial horizon as a primary instrument, while allowing for variations in speed and altitude within certain limits. Insufficient speed is to be avoided so as not to reduce buffet and stall margins. The ignition should be engaged in accordance with the operating manual.

1.5.2. *Operator's manual*

The operator's Operations Manual (part 8.3.8.1 "Storms", 2-12-2002) indicates that thermal turbulence is almost always associated with storms, and not just within storm cells; thus, the guidance in the manuals concerning flying in turbulent areas is also applicable to surrounding areas. Section 8.3.8.5 "Jet Stream" (2-12-2002) states (in keeping with ICAO guidance) that these streams, especially those resulting in winds in excess of 110 kt, are prone to generating CAT in the tropopause above the center of the stream and below the stream, and in the low pressure area, the turbulence being more pronounced above and to leeward of mountain chains. It gives indications for predicting the chances of encountering CAT based on horizontal and vertical wind shear, which in turn varies with the horizontal temperature gradient. In any case, it recommends adjusting the speed in areas where CAT is forecast or reported to that recommended for flying in turbulence as soon as the first jolt is experienced.

If CAT is encountered with a tail or head wind, a course or altitude change should be initiated since those areas are narrow and thin.

When experiencing CAT with a crosswind, it is generally not necessary to alter level or heading since the turbulence zones are narrow.

It also warns to monitor outside air temperature (OAT) if CAT is expected due to crossing into the tropopause. The lowest temperature in the flight path will indicate entry into the tropopause and the CAT will be more pronounced on the stratosphere side.

1.5.3. *Use of weather radar*

There is no indication that the crew had any problems with the use of the weather radar. Since the crew could see the cloud tops and lightning flashes, they did not need the radar to know they were approaching a stormy area.

Current on-board weather radars can only detect precipitation (water droplets, rain, hail, snow, etc.) inside clouds. Clear air turbulence or turbulence inside clouds without precipitation is not detected by this equipment. Considering this limitation, awareness of the situation and avoiding flying above or below hazardous clouds are the only means of preventing turbulence from affecting the aircraft.

The use of weather radar's TILT capability (i.e. the change of the angle of the antenna with respect to the horizontal) is considered one of the most critical factors in being able to detect the level of precipitation inside a cumulonimbus cloud and, via this indirect method, of anticipating any possible related turbulence. If this feature, along with selecting the adequate distance range, is not adequately used, the effectiveness of the weather radar could be reduced to the point where the flight crew may not be able to detect the hazard levels associated with a cloud area.

1.6. Types of turbulence

For the purposes of this report, the following two types of turbulence may be defined:

a) Clear air turbulence (CAT) which, according to Advisory Circular AC 61-107A, "Operations of aircraft at altitudes above 25,000 ft MSL and/or Mach numbers (Mmo) greater than .75" (2-1-2003), is "a meteorological phenomenon associated with high-altitude winds. This high-level turbulence occurs where no clouds are present and can take place at any altitude (normally above 15,000 feet AGL), although it usually develops in or near the jet stream where there is a rapid change in temperature. CAT is generally stronger on the polar side of the jet and is greatest during the winter months. CAT can be caused by wind shear, convection currents, mountain waves, strong low pressures aloft, or other obstructions to normal wind flow. CAT is difficult to forecast because it gives no visual warning of its presence and winds can carry it far from its point of origin."
b) Turbulence from cumulonimbus clouds: the aforementioned AC 61-107A states that "clouds with extensive vertical development (e.g., towering cumulus and cumulonimbus (CB) clouds) indicate a deep layer of unstable air and contain moderate to heavy turbulence with icing. The bases of these clouds are found at altitudes associated with low to middle clouds but their tops can extend up to 60,000 feet or more. Cumulonimbus clouds are thunderstorm clouds that present a particularly severe hazard to pilots and should be circumnavigated if possible. Hazards associated with cumulonimbus clouds include embedded thunderstorms, severe or extreme turbulence, lightning, icing, and dangerously strong winds and updrafts."

This type of turbulence is sometimes called "convection-induced turbulence" (CIT) since it arises from thermal convection. Of importance to operational safety is the fact that the effects of CIT are noticeable while the clouds where it is developing are still far off, and that the effects are generally worse below and to leeward of the CB.

FAA AC 00-24B, Thunderstorms, provides, among other things, the following guidance for avoiding the effects of thunderstorms:

Do avoid by at least 20 NM any thunderstorm identified as severe or giving an intense radar echo.

Do clear the top of a known or suspected severe thunderstorm by at least 1,000 feet altitude for each 10 knots of wind speed at the cloud top.

Do circumnavigate the entire area if the area has more than 60 per cent of thunderstorm coverage.

Do regard as extremely hazardous any thunderstorm with tops 35,000 ft or higher, whether the top is visually sighted or determined by radar.

If it cannot be avoided penetrating a storm, some recommendations to be applied before entering the storm are:

Establish power settings for turbulence penetration airspeed recommended in the aircraft manual.

If using automatic pilot, disengage altitude hold mode and speed hold mode.

If using airborne radar, tilt the antenna up and down occasionally to detect other thunderstorm activity at altitudes other than the one being flown.

If, in spite of everything, you penetrate an area affected by storm-induced turbulence, apply the following guidelines while crossing it:

Do not change power settings; maintain settings for the recommended turbulence penetration airspeed

Do maintain constant attitude. Let the aircraft "ride the waves".

Don't turn back once you are in the thunderstorm. The hazard can be increased and turning maneuvers increase stress on the aircraft.

2. ANALYSIS

2.1. Anticipated encounter with turbulence

The aircraft was flying at FL330 with the auto pilot and auto thrust engaged at Mach 0.81 near an area where the forecast chart, valid 3 hours earlier, was calling for the confluence of several adverse weather phenomena:

- Confluence of a jet stream in excess of 100 kt at FL390 with a cold front, which was expected to generate CAT over a rather wide area.

- Embedded and isolated cumulonimbus clouds from below FL250 up to FL350.
- Transition zone from tropical to polar tropopause.

The airplane was flying under the jet stream from the warm side to the cold (north), where the maximum turbulence exists.

The recommended penetration airspeed by Boeing was Mach 0.78. At that time, the onboard meal service was concluding. The crew had the clouds in sight and believed they were sufficiently far enough away from the storm area at all times to avoid feeling the effects of the convection-induced turbulence.

They initiated a turn to avoid the area and, upon noticing the first jolts, turned on the fasten seat belt sign.

These actions, however, were not carried out early enough since just 7 seconds later, the strongest disturbances started, with the maximum positive vertical acceleration being reached 12 seconds after having turned on the warning light. The abrupt aircraft movements took place while the cabin crew was still clearing the meal trays or returning to their seats, which led to injuries of varying intensity to several occupants.

Given the lack of exact data concerning the aircraft's horizontal and vertical distance to the cloud tops, it is difficult to determine whether CAT (associated with the jet stream) or CIT affected the airplane; that is, if the turbulence was due to the effects of the jet stream encountering the cold front, or to the influence of the cumulonimbus clouds extending more than expected and affecting the airplane, though the first possibility seems more likely, especially considering the drop in temperature that took place upon approaching the area (see Figure 4). The crew approached the event as a case of CAT since they had previously identified the storm front.

As indicated in 1.6 a), it is generally accepted that clear air turbulence "... normally develops in or near the jet stream where there is a rapid temperature change..." The operator's Operations Manual also warns to take notice of outside air temperature (OAT) if CAT is expected as a result of penetrating the tropopause.

In this case, between 03:21 and 03:23, a drop in OAT took place, recovering shortly before falling more noticeably at 03:25. A minute later the turbulence began. Only the constant monitoring of those temperature values and associated wind variations, if the presence of CAT had been foreseen, could have helped prevent the accident.

2.2. Effects of turbulence on the flight

Given the unexpected swiftness and initial violence of the encounter, it was difficult for the crew to react in the first few seconds. There was no time to reduce speed to that recommended for turbulence penetration.

At the start of the oscillations, the automatic pilot was engaged. It remained engaged and attempted to maintain the initial airspeed against any changes. Since the auto thrust was also engaged, there were significant changes in the engine thrust, which was reduced when the airspeed warnings were received. It is likely, however, that a rise and a subsequent drop in altitude, both very severe, took place which led to the abrupt acceleration changes felt in the cockpit.

According to the aircraft's operations manual, the automatic pilot was allowed to be engaged during light or moderate turbulence, unless changes in attitude or other parameters required manual control, as probably happened in this case once a 19° up angle was reached. The manufacturer's documentation suggests smoothly controlling the attitude. The operations manual recommends disengaging auto thrust.

After the first 60 seconds, during which the airplane suffered the worst effects from the acceleration, the crew was able to control the situation. They later informed ATC and requested a level and course change to avoid the turbulence. Later, with guidance provided by a doctor who was traveling onboard, they decided to continue to their destination despite the injuries suffered onboard, which is considered the proper choice under the circumstances and given that they had been flying for over three hours.

2.3. Risks faced by the cabin crew

Three accidents involving turbulence in international commercial aviation traffic were reported to the CIAIAC in 2004 and 2005, resulting in three serious injuries, two of them to cabin crew and the other to a passenger. The accidents affected three different operators and aircraft models.

In all three cases, it has been determined that, though the event may have initially appeared to be CAT, the presence of cumulonimbus clouds and storm activity had been forecast in the vicinity of the area where they occurred, which could have added instability to the surrounding air. This indicates the need to increase awareness concerning the large area beyond the clouds that could be affected by convection-induced turbulence so that the proper attenuating measures can be taken with as much anticipation as possible.

These measures should include providing enough time to ensure everyone aboard has their seat belt fastened and that there are no loose objects in the cabin.

It is common practice on commercial airline passenger flights to recommend to passengers that they keep their seat belts fastened at all times while seated, though there is no obligation to do so save during certain phases of flight or as required by the crew. This is done in an attempt to keep to a minimum passenger injuries due to turbulence, which is probably one of the leading causes of personal injury on commercial flights.

The current event, however, as well as those previously investigated, serves to highlight the risk from turbulence to cabin crew members, who are on their feet throughout many of the different phases of the flight, whether to perform a necessary onboard safety service or to carry out services of a more commercial nature, which are also of great importance to the companies.

By way of comparison, a study published in 2004 by the FAA on turbulence-related aviation accidents between 1990 and 2001 in the USA[2] indicates that 72 airline accidents (under FAR 121) took place in that period, resulting in 89 serious injuries and no fatalities. For purposes of the study, the types of turbulence (with the number of events and of serious injuries associated with each category in parentheses) were divided into "Turbulence" (24 events and 29 serious injuries), "Clear air" (23 and 27), "Turbulence in clouds" (14 and 19), "Thunderstorm turbulence" (9 and 12), "convection induced" (1 and 1) and "Mountain wave" (1 and 1).

3. CONCLUSION

The most likely cause of the accident is considered to be an unexpected encounter with severe turbulence in the vicinity of a jet stream and of a developing mass of clouds with storm activity, which led to a large rise and drop in altitude over a short period of time.

4. SAFETY RECOMMENDATIONS

Following the accident, the operator issued a series of internal company recommendations, which included increasing crew awareness to use all available weather information to avoid similar events, to maintain the maximum possible distance from cumulonimbus clouds, circling them to windward, to reduce airspeed to that recommended by the manufacturer if the possibility of experiencing turbulence exists, and, in case of any doubt, to delay, modify or even cancel the services provided to passengers and to turn on the seat belt sign.

Since the only parameters that could have helped in any way to anticipate the appearance of clear air turbulence were outside air temperature, as was generically described in the operations manual, and changes in associated winds, the following recommendation is issued to the operator:

REC 19/07. It is recommended that Air Europa provide transatlantic flight crews with detailed material to help them easily anticipate the presence of jet stream related clear air turbulence through the monitoring of static air temperature and associated winds.

[2] «Review of Aviation Accidents Involving Weather Turbulence in the United States 1992-2001», Reference number 04-551, FAA Office of System Safety, August 2004, página 14 y siguientes.