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COMISIÓN DE
INVESTIGACIÓN
DE ACCIDENTES
E INCIDENTES DE
AVIACIÓN CIVIL

Report IN-029/2006

Wake turbulence encounter in high-level air space involving an AIRBUS A320 aircraft, registration EC-JDK, operated by Vueling, in route between Barcelona and Santiago de Compostela on 28 May 2006

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MINISTERIO DE FOMENTO

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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 object of the investigation, and its probable causes and consequences.

In accordance with the provisions in Article 5.4.1 of Annex 13 of the International Civil Aviation Convention; and with articles 5.5 of Regulation (UE) n° 996/2010, of the European Parliament and the Council, of 20 October 2010; Article 15 of Law 21/2003 on Air Safety and articles 1, 4 and 21.2 of Regulation 389/1998, this investigation is exclusively of a technical nature, and its objective is the prevention of future civil aviation accidents and incidents by issuing, if necessary, safety recommendations to prevent from their reoccurrence. The investigation is not pointed to establish blame or liability whatsoever, and it's not prejudging the possible decision taken by the judicial authorities. Therefore, and according to above norms and regulations, the investigation was carried out using procedures not necessarily subject to the guarantees and rights usually used for the evidences in a judicial process.

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

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

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Abbreviations

00°	Degrees
00 °C	Degrees centigrade
ACAS	Airborne Collision Avoidance System
AD	Airworthiness Directive
ADIRU	Air Data / Inertial Reference Unit
ALT	Altitude
AOB	Angle Of Bank (degrees)
AP	Autopilot
ATC	Air traffic control
BEA	Bureau d'Enquêtes et d'Analyses
CAS	Calibrated Airspeed
CAT	Instrument approach category
CIAIAC	Spain's Civil Aviation Accident and Incident Investigation Commission
CLB	Climb
CM1	Left-hand pilot's seat
CM2	Right-hand pilot's seat
CRM	Crew Resource Management
CVR	Cockpit Voice Recorder
daN	Decanewton/s
DFDR	Digital Flight Data Recorder
DGAC	Spain's Civil Aviation General Directorate
DMU	Data Management Unit
E	East
EANPG	European Air Navigation Planning Group
ELAC	Elevator Aileron Computer
FA	Flight Attendant
FAA	Federal Aviation Administration
FAC	Flight Augmentation Computer
FAR	Federal Aviation Regulations
FBW	Flight by Wire
FCTM	Flight Crew Training Manual
FCOM	Flight Crew Operating Manual
FD	Flight Director
FDR	Flight Data Recorder
FL	Flight Level
ft	Feet
g	Acceleration due to gravity
GS	Ground Speed
h	Hours
hPa	Hectopascal(s)
IAS	Indicated Airspeed
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
JAR	Joint Airworthiness Regulations
kg	Kilogram(s)
KIAS	Indicated Airspeed (knots)
km/h	Kilometers per hour
kt	Knot(s)
l	Liter
lb	Pound(s)
m	Meter(s)
M	Mach number
ME-MP	Multiengine-Multipilot
ME-SP	Multiengine-Singlepilot
Mmo	Maximum Mach operating speed

Abbreviations

Msg	Message
N	North
N1	Engine fan speed in RPMs
NAV	Navigation
NDT	Non-destructive testing
NM	Nautical Miles
NTSB	National Transportation Safety Board
P/N	Part Number
PF	Pilot Flying
QAR	Quick Access Recorder
RA	Resolution Advisory
RVSM	Reduced Vertical Separation Minimum
S	South
S/N	Serial Number
SPD	Speed
TA	Traffic Alert
TAS	True Airspeed
TCAS	Traffic Collision Avoidance System
THR	Autothrust
Tm	Tons
UTC	Coordinated Universal Time
VFR	Visual Flight Rules
Vmcg	Minimum control speed on the ground
Vmo	Maximum operating speed
VS	Vertical Speed (ft/min)
W	West

Synopsis

Owner and operator:	Vueling
Aircraft:	AIRBUS A320; registration EC-JDK
Date and time of incident:	28 May 2006; at 12:36 UTC time[1]
Site of incident:	Airway UN-725, between points DIRMU and KUMAN
Persons onboard and injuries:	Pilot, copilot, five flight attendants (FA) and 135 passengers. Four passengers and three FAs were slightly injured
Type of flight:	Commercial air transport – Scheduled – Domestic passenger
Date of approval:	21 February 2011

Summary of incident

The aircraft, an Airbus A320, en route from Barcelona to Santiago de Compostela, passed through an area of strong turbulence while at FL325 that caused the aircraft to descend sharply while banking significantly to either side. As a consequence of the aircraft's sudden motion, four passengers and three flight attendants were slightly injured. The crew managed to stabilize the aircraft at FL310 and continue on to its destination.

The investigation revealed that this incident resulted from the wake turbulence of a preceding Airbus A340-300 that was on the same airway, 10.13 NM ahead of the Vueling Airbus A320-200 and on the same heading. It was also flying to point "Kuman" at FL330.

The crew's actions were not in compliance with the procedures for flying the aircraft and could have served to exacerbate the effects of the external disturbance.

[1] All times in this report are UTC. To obtain local time, add two hours to UTC.

1. FACTUAL INFORMATION

1.1. History of the flight

The aircraft had taken off from Barcelona airport at 14:19 local time. Its destination was Santiago de Compostela airport. There were 135 passengers and seven crew members onboard.

Twenty minutes into the flight, with the aircraft at FL325 on route UN-725 between points DIRMU and KUMAN and climbing to FL370, it crossed through an area of strong turbulence which caused the aircraft to bank sharply to the right. The autopilot, which was engaged at the time, attempted to counteract the bank, though its commands were insufficient to stop it given the intensity of the motion, as a result of which the bank continued.

At that time the pilot flying was the CM2.

In light of the situation, the CM2 took the controls, disengaging the autopilot. He first managed to stop the aircraft's banking motion, only to reverse it before finally leveling the aircraft, though immediately afterwards it started to bank to the right once again. The CM2 again took action to counteract this subsequent movement and leveled the aircraft, though seconds later the aircraft banked to the right for a third time.

The CM1 decided to take the controls of the aircraft, which he indicated to the CM2 by saying "I have the controls" and pushing the override button on the sidestick. The CM2 replied, "You have the controls".

The control problems described above were repeated a further four times; the difference being that these banking motions were to both sides, after which the crew managed to regain control of the aircraft.

As these events were taking place, the aircraft started to descend, eventually reaching FL303, at which time the crew regained control.

As a consequence of these violent motions to which the aircraft was subjected, four passengers and three flight attendants received minor injuries, caused mostly from bumps.

The aircraft was able to continue on its way and made a normal landing at its destination airport, Santiago de Compostela.

The DFDR data were downloaded and provided to the manufacturer for analysis.

A few days later, on 6 June, the aircraft operator was notified by the manufacturer that an analysis of the DFDR data had revealed that high lateral acceleration values, of up to +0.47g, had been reached during the event, thus requiring that the aircraft be subjected to a more in-depth inspection. At that time the aircraft was flying toward Valencia airport, so it was decided to park the aircraft at that airport, where the inspection ordered by the manufacturer was begun. Subsequently, on the 11th of that month, the aircraft made a ferry flight to Zurich airport, where the inspection was completed.

The inspection revealed that the aircraft could be returned to service, which it was on 26 June.

1.2. Injuries to persons

Injuries	Crew	Passengers	Total in the aircraft	Others
Fatal				
Serious				
Minor	3	3	6	Not applicable
None	4	132	136	Not applicable
TOTAL	**7**	**135**	**142**	

1.3. Damage to aircraft

Once on the ground, the aircraft was subjected to the inspections specified in the maintenance manual for flying in severe turbulence. All of the aircraft's components were found to be in perfect working order. The only damage observed was to the aft part of the galley, caused by the impact of a food service cart, and which affected the oxygen generator by door 2R, the galley oxygen module, some of the signs and lights on doors 2L and 2R. All of this damage was quickly repaired, which allowed the aircraft to make the return trip to Barcelona the same day with the same crew.

1.4. Other damage

There was no additional damage.

1.5. Personnel information

1.5.1. *Captain*

Age: 51

Nationality: Italian

Certificate of competence

License: Airline Transport Pilot License

Issue date: 28 November 2002

Expiration date: 28 November 2007

Ratings:

- Single Engine Piston (Land): Valid until 18/03/2007
- Multi-Engine Piston (Land): Valid until 20/05/2006
- A319/320/321: Valid until 12/06/2007
- ME-MP Instrument Flight: Valid until 12/06/2006
- ME-SP Instrument Flight: Valid until 20/05/2006
- Flight Instructor: Valid until 18/03/2007
- Previous ratings held: DC-8, DC-9, B777

Medical exam

Class: 1

Date of last exam: 17/03/2006

Valid until: 19/09/2006

Flight experience

Total flight hours: 14,000 h

Hours on the type: 1,800 h

Activity

The flight on which the incident took place was his first of the day. He had started his activity at 13:15 local time. He had had 13:13 hours of rest prior to the flight.

Since 21 April 2006, date on which he started flying for Vueling, the pilot had logged the following flight activity:

Date	Start time	Finish time	Activity	Maximum activity[2]
21/04	03:15	12:36	9:21	10:30
22/04	04:00	11:32	7:32	11:00
23/05	Rest			
24/05				
25/05				
26/05	11:15	20:34	9:19	12:30
27/05	11:15	22:03	10:48	12:30

[2] In accordance with Spain's Civil Aviation Authority (DGAC) Operational Circular 16B.

In the thirty days prior, his flight activity had been as follows:

	Number of flights	Hours
Previous 30 days	58	148:27 h
Previous 7 days	16	43:44 h
Previous day	4	10:48 h

1.5.2. *Copilot*

Age:	35
Nationality:	Dutch

Certificate of competence

License:	Airline Transport Pilot License
Issue date:	13 June 2002
Expiration date:	31 Mar 2011

Ratings:

- ATR42/72 (copilot VFR/IFR): Valid until 1/05/2006
- A319/320/321: (Captain VFR/IFR): Valid until 12/06/2007

Medical exam

- Class:	1
- Date of last exam:	20/07/2005
- Valid until:	1/08/2006

Flight experience

Total flight hours:	5,700 h
Hours on the type:	500 h

Activity

The flight on which the incident took place was also his first of the day. He had started his activity at 13:15 local time.

Since 2 April 2006, the copilot had logged the following flight activity:

Date	Start time	Finish time	Activity	Maximum activity
2/04	04:00	15:36	11:36	11:00
3/04	05:00	11:11	6:11	13:00
4/05	04:35	14:28	9:53	11:00
5/05	03:15	09:13	5:58	11:15
6/05	12:30	20:29	7:59	12:45
7/05	Rest			
8/05				
9/05				
10/05	11:21	20:35	9:14	12:30
11/05	15:40	20:49	5:09	13:00
12/05	11:15	20:43	9:28	12:30
13/05	12:05	21:25	9:20	12:00
14/05	15:40	21:17	5:37	13:00
15/05	Rest			
16/05				
17/05				
18/05	05:00	11:19	6:19	13:00
19-05	03:15	12:40	9:25	10:30
20-05	04:00	16:56	12:56	11:00
21-05	11:15	20:54	9:39	12:30
22-05	Rest			
23-05				
24-05				
25-05				
26-05	04:35	14:32	9:57	11:00
27-05	04:35	13:57	9:22	12:30

As is evident from the table, on 2 April and 20 May, the copilot exceeded the maximum activity limits, by 36 minutes in the first case and by one hour and 56 minutes in the second. In the latter, the crew's activity was prolonged as a result of a delay in the departure of the day's last flight, Brussels - Barcelona, caused by heavy traffic at the departure airport and by problems arising from a conveyor belt malfunction.

Article 7.1 of Operational Circular 16B establishes certain exemptions for compliance with the maximum activity periods, including the following: “the captain of the flight shall notify the DGAC of a potential violation of the maximum limits due to unforeseen circumstances in the five days following his return to the base. The circumstances involved shall be duly justified so that the suitability of the decision may be assessed. Flight activity time violations in excess of two hours shall only be considered acceptable under exceptional circumstances”.

His rest period prior to the flight had been 21:18 h. In the thirty days prior, his flight activity had been as follows:

	Number of flights	Hours
Previous 30 days	52	138:03 h
Previous 7 days	10	31:07 h
Previous day	2	9:22 h

1.5.3. *Proficiency check and training*

Captain

On 15 April 2006, the captain satisfactorily completed a proficiency check on the A320/200 aircraft as the CM1.

In the months prior to the incident, he had received training on the following subjects:

- CAT II/III instrument approach.
- A320 refresher.
- Crew resource management (CRM).

Copilot

On 13 January 2006, the copilot satisfactorily completed a proficiency check on the A320/200 aircraft as the CM2.

In the months prior to the incident, he had received training on the following subjects:

- CAT II/III instrument approach.
- A320 refresher.
- Crew resource management (CRM).

1.6. Aircraft information

1.6.1. *Airframe*

Manufacturer:	AIRBUS
Model:	A-320
Production number:	1769
Registration:	EC-JDK
Owner:	Vueling
Operator:	Vueling

1.6.2. *Maintenance information*

1.6.2.1. Maintenance Manual. In-flight turbulence

The aircraft's maintenance manual requires that an inspection be performed after flying through excessive turbulence or above Vmo/Mmo. So as to further specify those cases requiring the inspection, the maintenance manual indicates that it shall be conducted if the crew's report and/or DFDR and/or QAR data show that:

a) The turbulence or maneuvers caused a vertical load factor equal to or in excess of:

   + 2.5 g or –1 g (clean configuration).
   + 2 g or 0 g (with flaps or slats extended).

b) The speed was above Vmo + 20 kt (CAS).
c) The speed was above Mmo + 0.04 M
d) The vertical load factor was equal to or above –2 g or 0 g while flying above Vmo or Mmo.

Regardless of the above, the manual also states that this inspection is required if a "DMU load report 15" is generated in the post-flight report, which would indicate that excessive vertical acceleration values had been reached. In no case does the maintenance manual include any criteria on lateral acceleration values as indications that the airplane has experienced severe turbulence.

As for the inspection itself, detailed instructions are provided on which areas are to be inspected, mostly visually. These are:

- Fuselage.
- Pylons and nacelles.

- Horizontal stabilizer.
- Vertical stabilizer.

If any damage is found, the manual provides further instructions on the actions to take.

In this specific case, this inspection was conducted at Santiago de Compostela airport and did not reveal any damage. The maximum vertical acceleration values to which the aircraft was subjected during the event were 1.69 g and –0.45 g, which are below the thresholds specified in the maintenance manual, above which an aircraft inspection is required.

1.6.2.2. Complementary inspection

As a result of the high lateral acceleration values to which the aircraft was subjected, and that were detected while analyzing the DFDR data, the aircraft manufacturer notified the operator on 6 June of the need to ground the aircraft and subject it to a more in-depth inspection which Airbus had designed ad hoc for this case. The inspection included the following:

Detailed visual inspection of external and internal surfaces and of the wing structure, including the primary and secondary flight controls, the rear of the fuselage, the vertical stabilizer and the rudder.

This inspection did not reveal any abnormalities, aside from cracking of the paint and sealant in some areas. This led the manufacturer to require further inspections of these areas using non-destructive testing (NDT), which also revealed no damage.

In light of these results and of the load studies carried out by the manufacturer, it was decided by Airbus that the aircraft could be returned to service, which it was on 20 June.

1.6.3. *Information on the A-320 flight control system*

The A-320, a narrow-body, twin-engine, medium-range jet with a seating capacity for 150 passengers, was first flown in 1988.

In this airplane, the movement of the flight controls in the cockpit by the pilots is not mechanically linked to the flight control surfaces. In a FBW design, the steel wires and tubes of a conventional mechanical transmission system are replaced by electrical wires. Between these wires and the flight control surfaces are computers and electrical and hydraulic actuators. The movement of the controls in the cockpit does not correspond exactly to preset deflections of the control surfaces. Firstly, there is no control column and wheel at the piloting positions. There is instead a small handle commonly referred to as the sidestick (see Figure 1).

Figure 1. Sidestick

The pilot's and copilot's sidesticks move independently. They are not mechanically linked and both pilots can be performing different maneuvers simultaneously. The airplane interprets the maneuver being requested as the algebraic sum of the two inputs.

The resistance provided by the system to the sidesticks is independent of the aerodynamic forces on the control surfaces and independent of the forces being applied by the other pilot to his sidestick.

Either pilot may override the other's input by pressing his own sidestick's override button. The last pilot to press this button has control of the aircraft, and a light on the other pilot's instrument panel informs the non-flying pilot of this fact. It should be noted, however, that the other sidestick is overriden only while the override button is pressed. The system sounds an aural "... dual input..." message when both sidesticks are activated simultaneously.

1.6.4. *Surveillance and collision avoidance system*

The aircraft was equipped with an ACAS II collision avoidance system, which is able to detect any aircraft within its operating range that is outfitted with a transponder. This system has a screen that displays information to the crew on the position of each of these aircraft with respect to their own airplane and that sounds alarms based on the calculated collision risk.

The system's detection ability is limited to those "intruder" aircraft that trespass an imaginary cylinder that is centered about the aircraft. This cylinder has a 30-40 NM radius and a height of 19800 feet.

The system offers three levels of protection, depending on the decision time available to react to intruding aircraft which, from low to high risk level, is arranged as follows: intruders: < 20 NM: TA - 40 sec.; RA - 25 sec.

The first of these does not represent an immediate threat, and is thus shown on the screen as just a nearby aircraft.

Traffic alerts (TAs) inform the pilot of the presence of an intruder aircraft that may constitute a threat, and alert him so that he can react to a potential resolution advisory.

Finally, a resolution advisory (RA) informs the pilot of the presence of an aircraft that poses a threat and recommends an evasive maneuver that will guarantee adequate separation.

1.6.5. *Use of the rudder in transport category airplanes*

In February 2002, the NTSB, in concert with the BEA, issued a recommendation to aircraft manufacturers that they stress to operators what the structural certification standards are for the rudder and the vertical stabilizer, and that they emphasize the fact that certain maneuvers can result in the violation of design limits and even in structural failure.

In response, Airbus published Flight Crew Operating Manual (FCOM) bulletin no. 828/1 in June 2004, which noted the aircraft's structural certification requirements for the rudder and vertical stabilizer show how some maneuvers could lead to a violation of design limits and even to structural failure. As a result, this bulletin stressed the adequate use of the rudder while highlighting the certification requirements and design features for controlling the rudder.

Its main sections are as follows:

Yaw control

In flight, yaw control is provided by the rudder, while directional stability is achieved by way of the vertical stabilizer.

The rudder and vertical stabilizer are sized so as to achieve the following two objectives:

- Provide sufficient lateral control of the aircraft on cross-wind landings and takeoffs within published cross-wind limits.
- Provide positive control of the aircraft in the event of an engine failure under maximum asymmetrical thrust conditions at any speed above Vmcg (minimum control speed on the ground).

The rudder and vertical stabilizer are capable of generating sufficient yaw moment to maintain directional control of the aircraft.

The rudder deflection necessary to produce these yaw moments, and the resulting side slip angles, can result in significant aerodynamic loads on the rudder and vertical stabilizer.

Both the rudder and vertical stabilizer are designed to withstand the loads prescribed in the JAR/FAR 25 certification codes, where various lateral loading conditions are defined (maneuvers, gusts and asymmetric loading caused by an engine failure). This allows the required structural resistance levels to be achieved.

Certification requirements

Consistent with the JAR/FAR 25 certification requirements, the rudder and vertical stabilizer must be sized so they can withstand the loads specified in said certification standards for a range of speeds between the minimum control and maximum design speeds at altitudes from sea level to the maximum altitude for all weight variations and center of gravity limits. Basically, three conditions are assumed in the maximum load calculations.

a) With the airplane in straight and level flight at constant speed, the rudder is sharply turned to the maximum deflection angle possible for the present speed.
b) With the rudder deflected under the conditions indicated in the preceding paragraph, the aircraft will initially yaw until a transitory slip angle is attained. The slip will then stabilize at a lower, specified stationary angle.
c) With the airplane yawing at the stationary slip angle that corresponds to the rudder deflection indicated above, it is assumed that the rudder pedal is released to its neutral position.

The JAR/FAR 25 certification codes require that the yaw maneuvers be analyzed under the assumptions and conditions indicated above, and that the most severe loads placed on the vertical stabilizer and rudder be identified.

The same analysis must be applied to lateral wind gusts, banking maneuvers and asymmetrical engine failure conditions. The most limiting case and its associated loads provide the design bases for the vertical stabilizer and rudder.

The loads defined in the preceding paragraphs define the limit loads in accordance with the JAR/FAR 25 requirements. These loads correspond to the maximum in-service expected values.

As per JAR/FAR 25 requirements, the ultimate load is defined as the limit loads multiplied by a safety factor of 1.5.

The aircraft structure must be able to sustain limit loads without detrimental permanent deformations, and the ultimate loads without failure for at least three seconds.

Loads in excess of the above may lead to structural failure.

Finally, this FCOM bulletin warns that the certification requirements do not necessitate that the structure be designed to support loads derived from rapid and maximum or near-maximum movements of the rudder to the side opposite that in which the aircraft is slipping, and that such an action could result in loads above design, and even ultimate, limits, leading to structural damage.

Rudder control

The rudder is controlled by three actuators that are commanded via a cable that routes the signal from the pedals. To this signal are added the flight control commands (yaw damping and turn coordination are functions of the ELAC and the FAC).

The rudder deflection limiter, controlled by the FACs, is designed to gradually reduce the rudder's maximum deflection angle as the speed increases.

This, however, does not prevent the rudder from providing sufficient yaw control within the flight envelope, including engine failures under maximum asymmetrical thrust conditions, and allows for the lateral loads on the rudder and vertical stabilizer to remain with the certification limits.

The maximum deflection limit for the rudder is based on aircraft speed, as shown in Figure 2. Yaw maneuvers at low speeds require large rudder deflection angles. These are achieved by making large inputs to the pedals.

While the rudder's maximum deflection angle is limited at high speeds, the relationship between the pedal displacement and the rudder deflection remains constant. As a result, less force is required to achieve maximum deflection at high speeds than at low speeds.

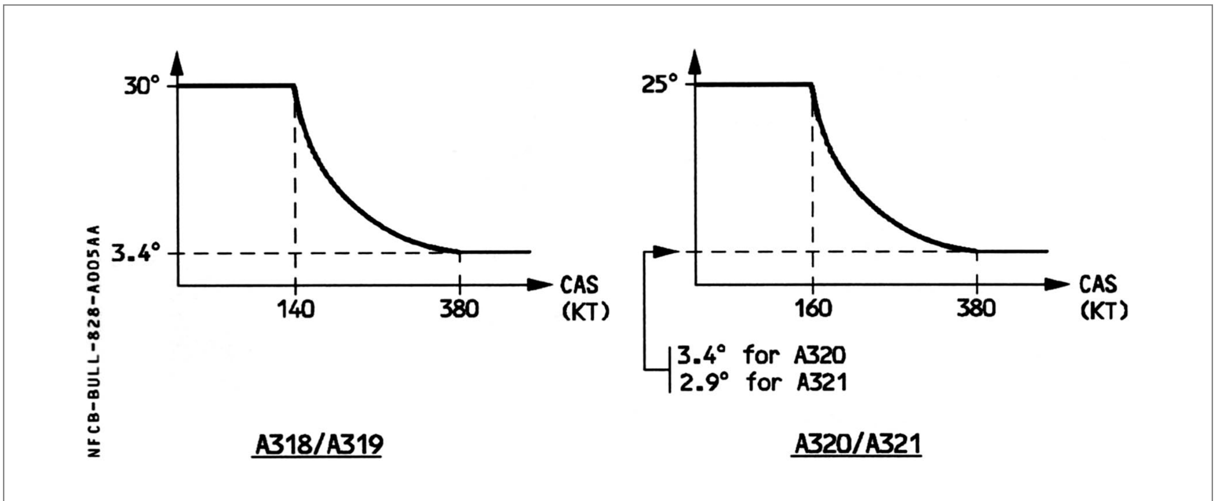

Figure 2. Relationship between speed and maximum rudder deflection angle

Operating recommendations

So as to avoid overloading the rudder and vertical stabilizer, the following recommendations must be observed:

1. The rudder is designed to control the aircraft in the following circumstances:

a) Lateral control in normal operations for the following cases:

- During the takeoff run, especially in cross-wind situations.
- During the flare in cross-wind landings.
- During the landing run.

b) To counteract thrust asymmetries:

Maximum rudder deflection can be used to compensate for yaw moments caused by a thrust asymmetry.

Note: at high speeds, thrust asymmetry has a relatively small effect on yaw, and thus can be offset by just a slight rudder deflection.

c) In other abnormal situations.

The rudder can also be used in abnormal situations, such as:

- A loss of the two yaw damping systems. The rudder can be used to coordinate turns, if necessary, so as to avoid excessive sideslip.
- Loss of rudder trim control. The rudder can be used to return it to its neutral position.
- Landings with abnormal landing gear positions. The rudder can be used for steering control of the aircraft on the ground.

In all of the above situations, both normal and abnormal, proper use of the rudder will not affect the structural integrity of the aircraft.

2 The rudder shall not be used:

- To induce a bank, or
- To counteract any turbulence-induced bank.

Regardless of the flying conditions, aggressive maximum or near-maximum inputs to one pedal and then the other must be avoided. Such an action could generate loads in excess of the limit load and lead to structural damage or failure.

The rudder deflection limiter is not designed to prevent structural damage or failure in the event of subsequent rudder pedal reversals.

As regards the Dutch roll[3], the action of the yaw damper and the aircraft's natural dampening are sufficient to neutralize the oscillations associated with this phenomenon. The rudder should not be used to complement the action of the yaw damper.

Under no circumstances should operator practices include the use of rudder pedal reversals (subsequent actions on a pedal and then on the other).

1.7. Meteorological information

There was no record of any temperature anomalies, clear air turbulence, mountain waves, wind shifts or any other phenomenon that could be related with this incident between altitudes of 34,000 and 37,000 ft.

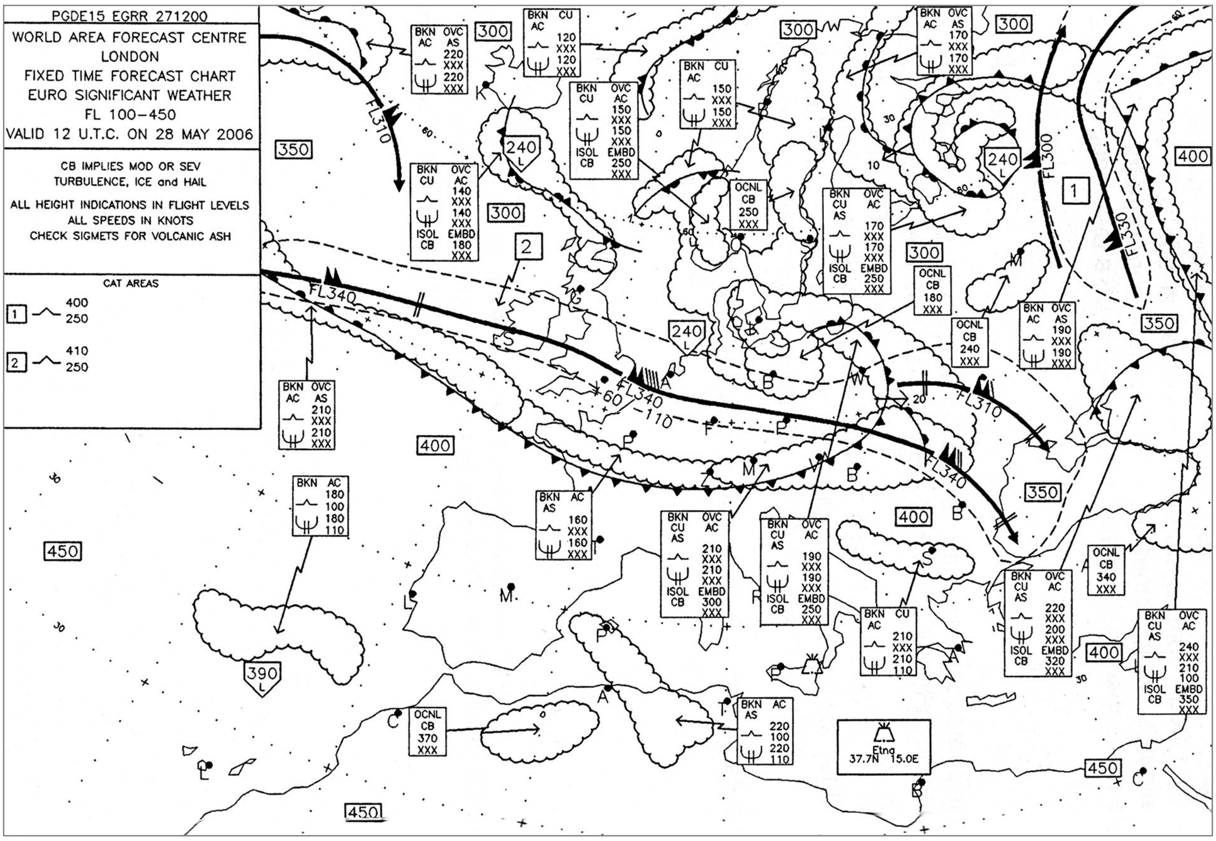

Figure 3. Chart issued by the World Area Forecast Centre

3 The Dutch roll is a lateral directional instability that is characterized by an oscillatory motion, a combination of yaw, slip and roll.

According with the information recorded in the DFDR the wind speed was practically constant of 10 kt, and its direction varied between 235° and 285°.

1.8. Aids to navigation

1.8.1. *Radar trace*

The flight's radar trace was analyzed for the period between 12:35:20 and 12:40:46 UTC, during which the event took place.

Initially, it was noted that the aircraft, transponder code 6326, was flying on a course of 288° en route to point "Kuman", at FL307 and climbing. Its ground speed was 453 kt.

At that time, only two other aircraft were present within a 20 NM radius of EC-JDK. One of them was behind, heading practically due south at FL350.

The other aircraft, an Airbus A-340-300, was on the same airway, 10.13 NM ahead of EC-JDK, on the same course and also flying toward "Kuman". Its ground speed was 464 kt and it was at FL330, that is, higher than the Airbus A-320.

At 12:36:31, which is when the aircraft started to cross the area of turbulence, the A-320 was at coordinates 41° 51′ 30″ N 00° 08′ 59″ W and at FL326. According to radar information, the other aircraft had crossed this same point at 12:35:11, that is, one minute and 20 seconds before, at FL330.

1.8.2. *Wake turbulence separation*

The provisions contained in the Air Traffic Regulations on the separation between aircraft due to wake turbulence refer almost exclusively to the approach and takeoff phases. The following table shows the separations for radar control.

Aircraft category		Minimum radar separation for wake turbulence
Preceding aircraft	Following aircraft	
HEAVY	HEAVY	7.4 km (4 NM)
	MEDIUM	9.3 km (5 NM)
	LIGHT	11.1 km (6 NM)
MEDIUM	LIGHT	9.3 km (5 NM)

On route mínimum separations are applied, both for wake turbulence (5 NM/1,000 ft) and for instrumental flight rules (IFR), which magnitude depends on the radar control, according to the following table (the bigger of the two must be applied)

Selection Mode	Process type	Separation
Normal	Multiradar	8 NM
Autonomous		
Autonomous	Single radar (civil radar station)	10 NM
Autonomous	Single radar (military radar station)	15 NM

The radar monitoring involved in this incident was multiradar, so the minimum separation was 8 NM, which is bigger than the wake separation.

1.9. Communications

1.9.1. *Communications between the aircraft and the Barcelona Control Center*

The aircraft and Barcelona Control Center times were synchronized using data from the flight recorder and from the communications exchanged between the aircraft and the Control Center. There was a three-second gap between the two, such that the time at the ATC station is three seconds later than the aircraft's.

What follows is a summary of the communications maintained between the aircraft and the Control Center, whose time was decreased by three seconds so as to synchronize it with the aircraft's.

At 12:31:07, the crew of flight VLG1190 established contact with the WA2 route sector of the Barcelona control center and reported it was climbing to FL290. The controller acknowledged the identification and notified EC-JDK to climb to FL310, which the crew acknowledged.

Thirty seconds later the controller called the aircraft again and asked that they climb to non-standard FL340. This request was properly acknowledged by the crew.

One minute after this exchange, at 12:32:45, the controller again contacted the aircraft to instruct them to climb to FL370, which the crew acknowledged.

At 12:36:53, four minutes after the last communication, the aircraft crew called the controller, requesting to descend because of turbulence.

1.10. Aerodrome information

Not relevant to the investigation of this incident.

1.11. Flight recorders

1.11.1. *Cockpit voice recorder*

Though the aircraft was equipped with a cockpit voice recorder (CVR) with a two-hour recording time, it was not possible to retrieve the information relevant to the incident since it was taped over on the return trip to Barcelona.

1.11.2. *Flight data recorder*

The aircraft was equipped with a digital flight data recorder (DFDR), Honeywell P/N 980-4700-042 and S/N 04262, which is able to record 550 parameters and whose information was subsequently downloaded.

The analysis was centered mainly on the time period from 12:36:00 to 12:39:20, which was divided into four event phases: pre, initiation, duration, and post.

Figure 4 shows the information on the position of the pilot's and copilot's sidesticks for both bank and pitch, as well as aileron positions and aircraft roll angle for the time between 12:36:30 and 12:37:10. Negative roll values indicate a left bank angle.

Figure 5 shows the position of the rudder and rudder pedals between 12:36:30 and 12:37:10.

Figure 6 provides information on lateral and vertical accelerations between 12:36:30 and 12:37:10, as well as on N1 for both engines between 12:36:30 and 12:39:20.

Finally, Figure 7 displays values for wind direction and speed between 12:36:30 and 12:37:10, as calculated by the airplane's inertial navigation systems

1.11.2.1. Pre-event (until 12:36:32)

Immediately prior to the event, the aircraft was in a clean configuration and climbing through FL325 for FL370. Its weight was 61 Tm and autopilot 2 (AP2 in CLIMB/NV modes)[4] was engaged. The autothrust was also engaged and active (Mach target 0.78).

[4] CLIMB/NAV: autopilot mode which provides vertical control to a selected altitude and lateral control for the duration of the flight plan.

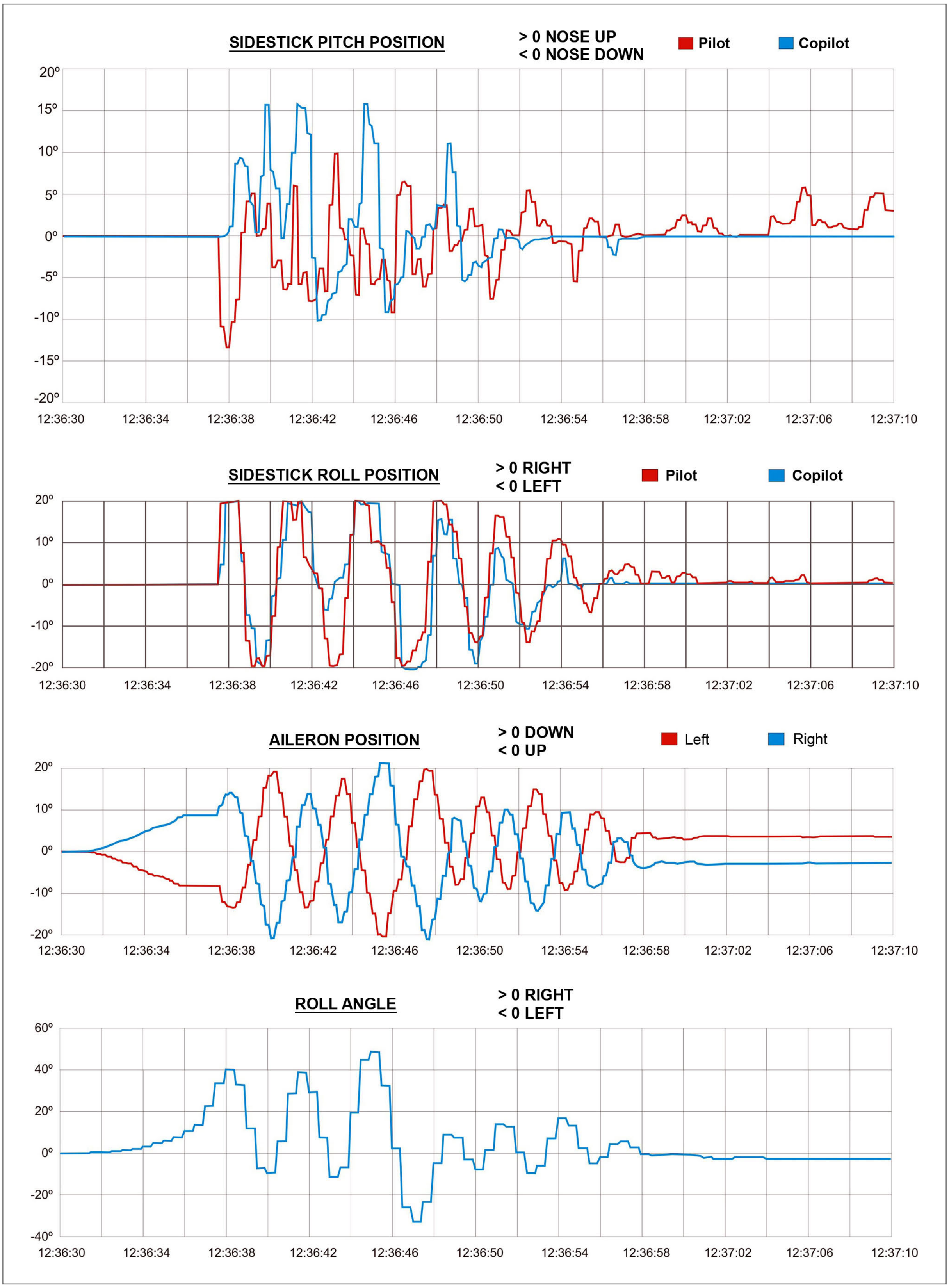

Figure 4. Positions of flight controls, ailerons and roll angle

In the 30 seconds prior to the event the wind varied from from 269° to 282° at a constant speed of 10 kt.

1.11.2.2. Event initiation (between 12:36:32 and 12:36:39)

Figure 4 shows how, at 12:36:32, the aircraft started to bank right, which the autopilot counteracted by deflecting the ailerons, eventually reaching the maximum allowable deflection to autopilot, which is 8° when at speeds in excess of 250 kt. Despite this, the bank angle continued to increase, prompting both pilots to respond, at 12:36:37, by providing inputs to the sidestick in both the pitch and bank directions. The sidesticks were moved to their maximum left positions and the left pedal was displaced 10°, which resulted in a rudder deflection of 5.2° to the left.

One second later, at 12:36:38, the roll angle reached 40.4° to the right, after which it started to decrease in response to the crew's inputs.

At the same time the autopilot was disengaged. The autopilot may be disengaged by any of the various conditions listed below:

- The override button is pressed on either sidestick.
- The corresponding AP pushbutton is depressed.
- A force above a set threshold is applied to either sidestick or to the pedals.
- The roll angle exceeds 45°.
- The pitch up angle exceeds 25° or the pitch down angle exceeds 13°.

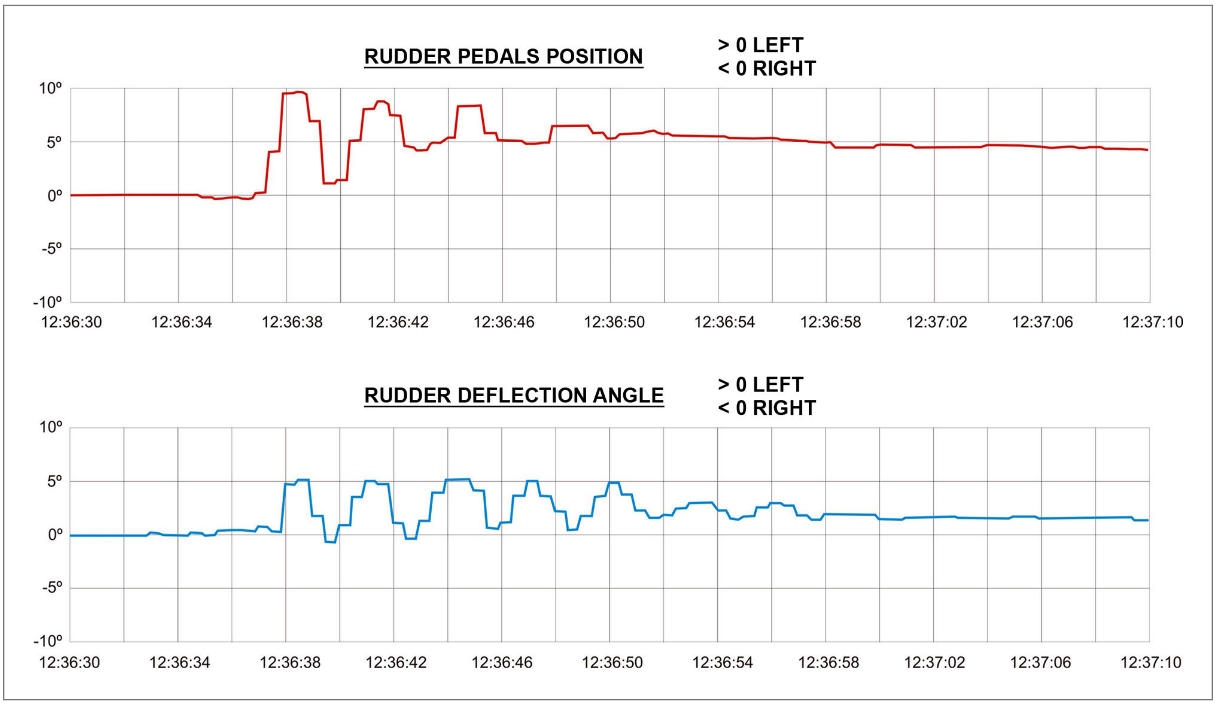

Figure 5. Rudder pedal position and rudder deflection angle

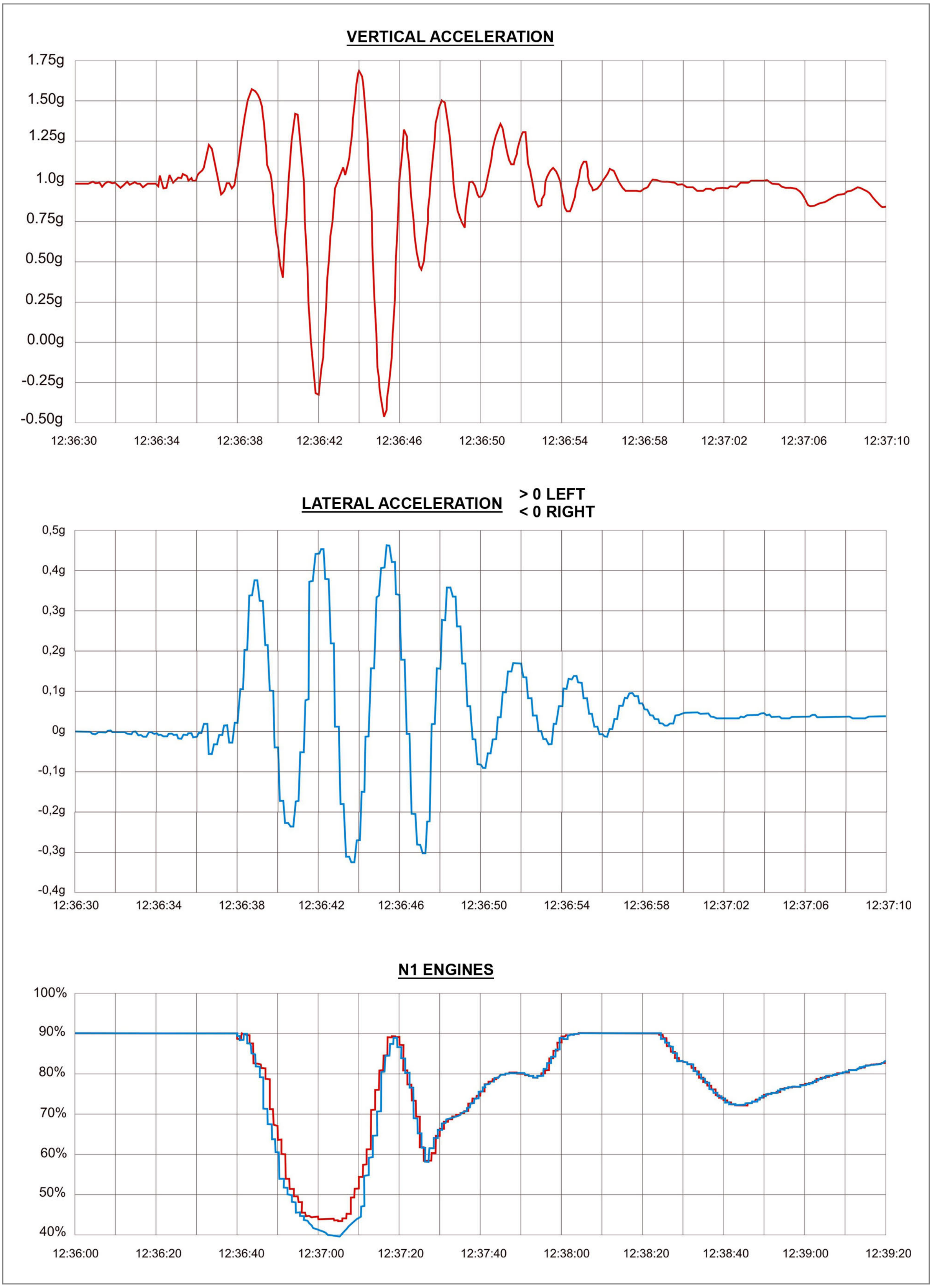

Figure 6. Vertical and lateral accelerations and engines N1

In this case the disengagement was produced by the crew actions on the sidesticks.

One second later, at 12:36:39, both sidesticks were positioned full to the right, the left pedal displacement was reduced to 1.7° and the rudder deflection was 0.6° right, which resulted in a decrease in roll angle to –9.1° (negative values indicate a left bank).

The relative wind (as felt by the aircraft) varied in direction from 272° initially to 285° and finally to 318°, with the speed increasing from 10 kt to 19 kt.

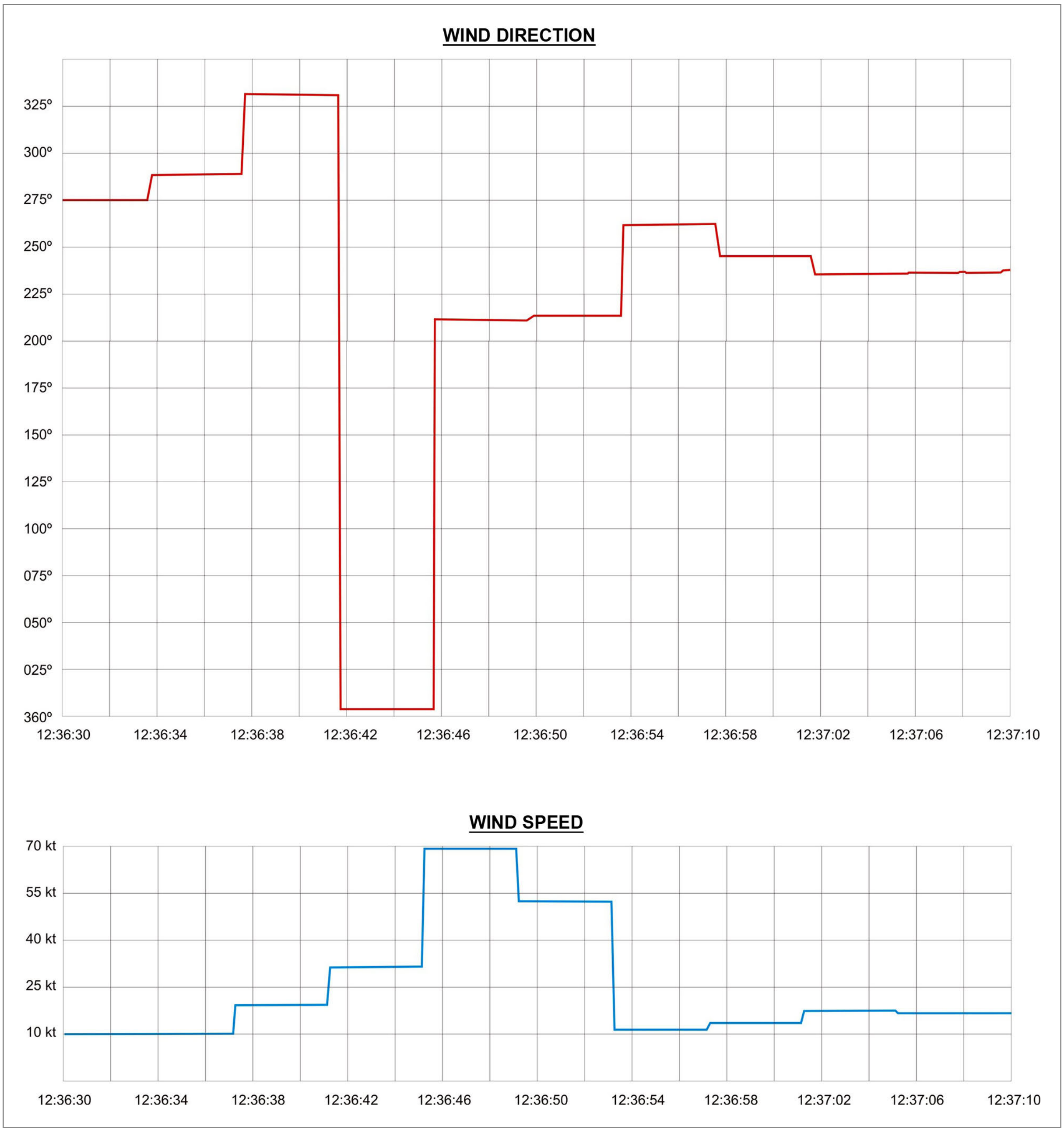

Figure 7. Wind direction and speed

1.11.2.3. During the event (12:36:40 to 12:36:51)

In the time period between 12:36:40 and 12:36:47, over four separate shifts in bank angle to either side were recorded. These were counteracted by the crew's inputs to the sidesticks to their maximum bank positions. The roll angle increased, reaching values of 33° left and 49° right.

During these seven seconds, two inputs to the left rudder pedal were recorded. The first input reached a value of 9.3°. The pressure on the pedal was then decreased to 4.8°. A subsequent input resulted in a 9° angle, followed by another pressure decrease to 5.7°. As a consequence of these actions, the rudder reached its maximum deflection value of 5.2°, coinciding with the value for the maximum right roll angle.

At 12:36:40, the throttles were slightly pulled back. This was followed by various inputs to the throttles until, at 12:36:49, they were retarded even more, almost to the flight idle position.

At 12:36:42, the wind direction shifted from 318° to 002°. This was accompanied by an increase in speed to 31 kt. Three seconds later it changed direction to 207° and the speed increased to 69 kt. At 12:36:49 the direction remained constant, but the speed had decreased to 52 kt.

The vertical acceleration peaked at values of –0.45 g and 1.69 g.

From 12:36:47 on, and over this entire period, the left pedal was actuated, the input value being close to 6°. Some variations were recorded in the rudder position.

During this time interval, the following warnings were received:

- 12:36:40: Warning roll discrepancy, which activated the "Master Warning" for two seconds.
- 12:36:43: Warning roll discrepancy msg.
- 12:36:44: Low oil pressure in engine 1 for one second.
- 12:36:45: Warning roll discrepancy msg and "Master Warning" for three and one seconds, respectively.

1.11.2.4. Post event (after 12:36:52)

The CM1 made several inputs to his sidestick, commanding a nose down attitude and producing the consequent descent of the aircraft.

At 12:37:05, the autothrust was disengaged.

At 12:37:08, the selected altitude was changed to FL300 and the throttles for both engines were returned to "climb". A second later the flight director (FD) mode was changed to VS (vertical speed selected to 2,000 ft/min) and the autothrust mode was changed to SPD (speed).

The left pedal deflection was decreased to 5°, which in turn decreased the rudder deflection to 1.5°. The aileron deflections were 2.6° for the left and –3.8° for the right. The lateral load factor reached 0.05 g and the roll angle was –2.8°.

At 12:37:18 the autothrust was again engaged.

At 12:37:25 autopilot 2 was again engaged (VS/NAV).

The pressure on the left pedal was slowly and gradually decreased. The input remained above 2° until 12:39:56, after which it dropped below that value, though it remained above 1.5° for over eight minutes. The rudder and ailerons returned to their neutral positions. The lateral load factor was 0.05 g to the right and the roll angle was –2.8°.

At 12:37:51 the autopilot mode was changed to OPEN CLB[5] and the altitude was selected to FL310.

At 12:38:01, N1 reached 90% and the autothrust mode was changed to CLB. The altitude was 30300 ft and increasing.

At 12:38:23, the autopilot mode was changed to ALT[6] (the ALT was 30,600, with 31,000 selected) and the autothrust mode was changed to SPD.

The selected altitude of FL310 was finally reached at 12:38:48.

Between 12:36:52 and 12:37:06, the following values were recorded for wind direction and speed: 210° - 52 kt, 258° - 11 kt, 242° - 13 kt and 230° - 17 kt.

The flight continued without any further incidents and landed at the Santiago de Compostela airport.

1.12. Wreckage and impact information

Not applicable.

[5] OPEN CLB: autopilot mode that maintains a speed (SPD/MACH) in PITCH mode, which controls either a selected speed or Mach or a vertical trajectory while the autothrust, if engaged, maintains maximum climb thrust.

[6] ALT: autopilot mode that maintains a set altitude.

1.13. Medical and pathological information

Of the 142 people onboard the aircraft, only six were slightly injured. The extent of their injuries was as follows:

- Passengers:
  - PAX 1: Head and back bruises.
  - PAX 2: Shoulder dislocation.
  - PAX 3: Head and leg bruises.
- Flight attendants:
  - FA1: Occipital contusion, one broken rib and several edemas.
  - FA2: Multiple contusions and a head laceration.
  - FA3: Multiple contusions.

1.14. Fire

There was no fire.

1.15. Survival aspects

The fasten seatbelt sign was off when the severe turbulence started to affect the aircraft.

The CM2 immediately turned on the sign.

Once the turbulence subsided, the crew attempted to communicate with the passenger cabin over the intercom system, which up to that point had functioned correctly. This attempt was unsuccessful, however, since the system was inoperative. The system was then reset, after which it worked properly again.

1.16. Tests and research

1.16.1. *Crew statements*

Captain

The takeoff from Barcelona and the initial climb were uneventful. Prior to the flight he had checked the weather information, which showed perfect conditions for flying. This coincided with the actual conditions they encountered during the flight. The wind at FL340 was two or three knots. They were initially cleared to FL310 in anticipation of FL340. Before reaching FL340 they were cleared through to FL370.

As they were reaching this level, they felt a sudden drop in altitude, after which the airplane moved violently to the right and then to the left. The oscillations continued as the airplane kept lurching without giving any indications of stopping. The PF at the time was the copilot (CM2). After two or three banking motions the autopilot was disengaged. He initially thought that it had disengaged automatically due to oscilations, but the CM2 confirmed that he had disengaged it. He thought the oscillations would stop after banking three or four times. He pressed the override button on his sidestick and said loudly “I have the control”. He moved the controls gently, without any abrupt inputs, as he carefully attempted to counteract the oscillations. He was finally able to regain control at FL340 or 330.

During the oscillations, they tried to select the start switch to ignition on both engines, but they could not reach the switches due to the dips and the vibrations. He disengaged the autothrust and controlled the throttles manually, reducing power to idle. He thought, this way, if either engine stopped, any asymmetrical thrust would be minimized.

They subsequently informed ATC of the event. ATC told them to maintain FL330. He noted that ATC had not informed them of the presence of another aircraft nearby. For their part, neither pilot had detected any other airplanes, either visually or on TCAS.

He added that he had never experienced anything similar. Only once when flying a B777 did he encounter strong turbulence, but it paled in comparison to this event.

Lastly, he noted that he did not recall having heard the “dual input” message.

Copilot

He agreed with the captain in that the weather information available to them at the pre-flight briefing did not show anything out of the ordinary, as a result of which they did not expect any turbulence. He likewise stated that he was the PF and that he performed the takeoff. While over Zaragoza, ATC cleared them to FL340. They were subsequently cleared to FL370. Before reaching that flight level, the airplane started to bank to the right, which surprised him. He disengaged the autopilot and attempted to control the airplane’s bank angle.

The airplane was moving so violently that both pilots feet lost contact with the pedals. He engaged the “Fasten seat belt” sign and heard the “dual inputs” message. He then heard the CM1 state "I have the control", after which he yielded the controls, saying "you have control".

He then contacted ATC, requesting a lower altitude. They were cleared to proceed to FL310.

He could not say whether any other airplanes were on the TCAS display as the turbulence started. Before this, he only remembered having seen one other aircraft on TCAS crossing their path some 20 or 30 NM away.

Lastly, he noted that he did not step on the pedals during the event, and that even had he wanted to, he would not have been able to since his feet were "floating" due to the aircraft's abrupt motions, which sent the manuals in the cockpit crashing into the walls.

1.16.2. *Load analysis*

The aircraft manufacturer, Airbus, conducted a load study for the purpose of determining whether any limit loads had been reached. The DFDR data and simulation models were used in this analysis.

An evaluation of the lateral loads confirmed that the vertical stabilizer and rudder had been subjected to loads of 125% of the limit load value. The maximum theoretical resistance of the tail prior to failure is 150% of the limit load.

The wing tip and the aft section of the fuselage were subjected to loads below the limit load.

1.16.3. *Determination of external turbulence*

An attempt was made to determine the basic parameters of the external turbulence through the use of simulation models. This was done by entering the values of the commands input by the crew to the flight controls and comparing the results to the actual data from the flight.

This analysis revealed that it was not possible to accurately determine the characteristics of the turbulence for three reasons: the highly dynamic characteristics of the event, the fact that it affected all three axes (pitch, bank and yaw) and the interaction between the three axes.

The results were still useful in verifying the extreme intensity of the turbulence.

1.17. Organizational and management information

1.17.1. *Operations manual*

1.17.1.1. Flying in turbulence

In the Flight Crew Operating Manual (FCOM), specifically in the chapter on adverse meteorological conditions within the “Supplementary Techniques” section, there is a part devoted to flying in severe turbulence that provides guidance on this subject.

Firstly, it indicates that, whenever possible, flying in areas with known or foreseeable turbulent conditions should be avoided.

Should such areas not be avoidable, the FCOM offers the following instructions:

Autopilot/autothrust

- Keep the autopilot ON.
- If the changes in engine thrust become excessive, disengage the autothrust.
- Use autothrust on approach to control speed.

Thrust and airspeed

The proper amount of thrust must be selected so as to maintain the IAS/MACH recommended in the relevant table and which is a function of the aircraft weight and flight level.

Specifically, the recommended speeds are 0.76M for FL330 and 275 KIAS for FL310, which require N1 of 81.2% and 80.4%, respectively.

The aircraft’s speed at the onset of the event was 0.78M with an N1 of 90.0%.

Only the thrust should be modified in the event of significant airspeed variations, in which case no effort should be made to reach the Mach number or airspeed.

A temporary increase is preferable to a loss of speed.

This section of the FCOM does not provide any guidance on the use of the flight controls in these situations. The Flight Crew Training Manual (FCTM), on the other hand, does indicate that when flying in these conditions, if the aircraft is flown manually, the crew should be aware of the fact that the flight control laws are, by themselves, designed to handle turbulence. The crew should therefore avoid the temptation of attempting to counteract the turbulence by using excessive sidestick inputs.

At a later stage Airbus amended the A320 flight manual, including instructions for the use of the controls by adding a warning on the maximum design maneuvering speed.

1.17.2. *Flight safety organization at the operator*

The aircraft operator did not have the capability to process and analyze the information from the flight data recorder. At the time of the incident, the procedure followed by the operator consisted of downloading the QAR data onto a card, which was then sent for analysis to a laboratory run by an outside company.

The operator has started to implement a system called Flight Operations Monitoring, through which the data from the flight recorders are sent to the manufacturer via internet for processing. The results of the analysis are then returned to the operator in the same way. This system allows for a considerable reduction in the elapsed time between data download and the availability of the findings.

1.17.3. *Safety measures taken by the operator*

The operator's in-flight safety department identified two aspects, one involving the notification of these events to the CIAIAC, and the other involving the crews, and adopted the following measures:

It modified its operating procedures so as to prevent having a crew involved in an incident from flying again on the same day.

It prepared cards with instructions on the procedure to be followed by the crews of those flights that may have been involved in some type of incident. These cards include precise indications regarding the preservation of the data contained on the aircraft's recorders so that they may be available in the investigation of the events.

1.18. Additional information

1.18.1. *Prior events involving high lateral loads*

The investigation by the National Transportation Safety Board (NTSB) into several cases of wake turbulence encounters in flight that occurred in the late 90s and early in last decade revealed that the aircraft involved in said events had been subjected to lateral accelerations in excess of 0.4 g, which produced loads in the attachment of the vertical stabilizer above the ultimate certified loads, and for which there was no specific procedure in the maintenance manual.

As a result of this, the Federal Aviation Administration (FAA) issued Airworthiness Directive (AD) 2002-06-09, which affected Airbus models A300, A-300-600 and A310. This AD contained inspection procedures applicable in the event of lateral acceleration events in excess of 0.3 g but below 0.35 g. If the acceleration was in excess of 0.35 g, the aircraft could not be returned to service without first being inspected directly by the manufacturer.

Similar events involving several aircraft types different from those affected by the AD mentioned above subsequently took place. This drove the NTSB, on 4 September 2003, to issue safety recommendations A-03-41, A-03-42, A-03-43 and A-03-44, which state:

A-03-41. Require all manufacturers of transport-category airplanes to review and, if necessary, revise their maintenance manual inspection criteria for severe turbulence and extreme in-flight maneuvers to ensure that loads resulting from positive and negative vertical accelerations, as well as lateral accelerations, are adequately addressed.

A-03-42. Require all manufacturers of transport-category airplanes to establish and validate maximum threshold values for positive and negative vertical and lateral G accelerations beyond which direct manufacturer oversight and intervention is required as a condition for returning the airplane to service.

A-03-43. Require all operators of airplanes that have experienced accelerations exceeding the threshold values established as a result of Safety Recommendation A-03-42 (or that the operator has reason to believe might have exceeded those thresholds), as determined from FDR and other available data, to notify the FAA immediately of such high loading events and provide all related loads assessment and inspection results.

A-03-44. Require manufacturers of transport-category airplanes to immediately notify the appropriate certification authority of any event involving accelerations exceeding the threshold values (or that the manufacturer has reason to believe might have exceeded those thresholds) necessitating the intervention of the manufacturer, and provide all related loads assessment and inspection results.

As a consequence of these, the FAA initiated a series of actions to create a working group, which would include various organizations from the world of aviation, and whose purpose would be to study the aspects involved in the recommendations, as well as the way to implement them.

1.18.2. *Prior wake turbulence events*

At the 47th meeting of the European Air Navigation Planning Group (EANPG), and subsequently of the ICAO working group, on the implementation of RVSM (Reduced Vertical Separation Minimums), held from 27 February to 1 March 2006, an incident involving an encounter with wake turbulence was studied. The incident took place on 13 August 2005 and involved two aircraft, an Airbus A-340-500 and a Boeing 757-200. The event is summarized below.

Both aircraft were flying east. The B-757 was at FL360, while the A-340 was 2000 feet lower and behind the Boeing, though its speed was 30 to 35 kt higher. As a result of its greater speed, the A-340 caught up to and overtook the B-757.

When the A-340 was 7 NM ahead of the B-757, the pilot of the former requested to climb to FL370, which was approved by ATC. The aircraft started to ascend gradually. At that time, the ground speeds of both aircraft were practically the same.

Just as the A-340 reached its requested flight level, FL370, the B-757 shook violently and started banking to the left, eventually reaching a bank angle of at least 45°. Immediately afterwards the aircraft started to descend. The pilot managed to arrest the aircraft's roll and then made inputs to the elevator to stop the descent. The aircraft lost 400 ft over the course of the event.

As a consequence of the abrupt motions, three flight attendants and two passengers were slightly injured.

An analysis of the event concluded that:

- The encounter with the wake turbulence was violent in nature.
- Wake turbulence encounters at high altitudes are generally not as violent.
- The separation between the two aircraft at the time of the event was double that normally required.
- So as to determine the course of action to take, all incidents involving wake turbulence that take place in EANPG member states are to be reported to the ICAO's EUR/NAT Office.

1.19. Useful or effective investigation techniques

Not used.

2. ANALYSIS

2.1. General

An analysis of the facts, as deduced from the available information, shows that the flight from Barcelona to Santiago de Compostela was uneventful until the moment when the aircraft encountered severe turbulence.

Meteorological information indicated the presence of a high pressure area to the west of Portugal. The pressure gradient over the Iberian Peninsula was almost constant and no significant weather events were forecast for the peninsula. Winds aloft were basically from the north and, in the area of the incident, did not exceed 15 kt.

An analysis of the weather information reveals that the general situation in the area at the time of the incident did not contribute to the turbulence encountered, though the atmospheric stability and the low, steady winds were conducive to preserving the wake turbulence conditions.

This hypothesis is supported by the fact that none of the other aircraft that flew in the area of the incident, either before or after the event, reported any turbulence to ATC.

At the start of the incident, the weight of the aircraft was 61.2T. The autopilot (AP2) was engaged in CLB-NAV mode. The autothrust was engaged (THR); Mach target: 0.78. The CM2 was the pilot flying, PF, in automatic flight mode, meaning that the autopilot and autothrust were engaged as the airplane climbed through FL325 to FL370, the level that had been authorized by Barcelona Control and acknowledged by the crew.

Starting at 12:36:37, the relative wind speed, which until then had been 10 kt, started to increase, reaching a maximum value of 70 kt eight seconds later. This value persisted for four seconds, after which it quickly dropped to pre-event levels.

Simultaneous with this variation in wind speed was a change in its direction. Whereas seconds before the wind had been from 275°, at the start of the event the direction started to shift rapidly in a clockwise direction, rotating through 360° before returning to its initial direction after 20 seconds.

However, it must be taken into account that the accuracy of the speed and wind direction values recorded in the DFDR is relative, as they are calculated from the difference between the ground speed (GS) and the true airspeed (TAS) for the intensity and from the trajectory direction and course of the aircraft for the direction. They are affected too by the following two factors:

- Yaw movements. During a temporary yaw movement, the value at the center of gravity may be different from that at the ADIRU. However, as soon as the yaw establishes, both values should be the same.

- The allowance of each parameter, which are as follows for this case:

  — Ground speed: ± 8 kt
  — True AirSpeed: ± 4 kt
  — Trajectory: ± 2.3° with GS = 200 kt
  — Course: ± 0.4°

The immediate consequence of this perturbation was a rapid and pronounced bank to the right, which the autopilot initially tried to counteract. Maybe the abruptness of this movement made the crew to counteract, which resulted in the autopilot to disengage. At this very moment the aircraft had a right bank angle of 20°.

The right bank continued until an AOB (angle of bank) of 49° was reached. This was followed by a left bank angle that reached 33°.

Such bank angles, as well as the vertical load factor produced in the aircraft before the actions of the crew perfectly match with the effects a wake turbulence encounter suffered by the aircraft.

From the ATC information, it is known that an Airbus A-340, at FL330. was 10.13 NM ahead of EC-JDK.

In all likelihood this points to the cause of the perturbations felt by the aircraft as resulting from encountering the wake turbulence from the Airbus A340 ahead of it.

The strength of the vortices generated by airplanes depends on several factors, as the aircraft weight, speed, configuration, wing lengthiness, attack angle, etc. Though the mechanisms by which the wake turbulences disappear are still not clear, the studies so far indicate that both the mixing action of the eddy viscosity and the interaction between the vortices themselves have an effect on them. There are other factors that may have influence in the duration of the vortices: the wind intensity and direction and the mechanic turbulence, which both accelerate its dispersal, or the atmospheric stability, which retards it. In this specific case the high atmospheric stability probably contributed to increasing the time to dispersal even more.

2.2. Crew actions

2.2.1. *Inputs to flight controls*

As previously indicated, as soon as the banking started as a consequence of the turbulence, the autopilot's intervention followed, trying to counteract it. Seconds later the crew's actions on the sidesticks led to the autopilot to disengage, as noted in the previous point. The procedure for a wake turbulence in flight states that the crew must not act in the pedals or in the sidesticks, and must allow the autopilot to manage the situation. In case the magnitude of the event surpass the management capacity of the autopilot, any of the circumstances leading to its disengaging must be reached, in which case an action from the crew is then expected.

According to the crew's statements, at the time the captain took the controls he pressed the override button and verbally stated to the copilot that he was taking the controls by saying, "I have the control". The copilot, according to his own statement, immediately released his sidestick and noted this to the captain by saying, "You have control". This course of action is entirely in accordance with the dual input procedure, the purpose of which is to impede simultaneous inputs to the two sidesticks. This being said, had the events in fact occurred as described, there would have been practically no dual inputs. This is clearly in conflict with the DFDR data, which show both pilots providing simultaneous inputs to their sidesticks starting practically at the same time and continuing for 21 seconds, from 12:38:37 to 12:38:58.

During the 21 seconds of dual inputs to the sidesticks, aural "dual inputs" messages sounded in the cockpit. The captain states that he did not hear the messages. The copilot did hear them, although he immediately released control to the captain when he did so. Likewise, the copilot did not notice the luminous signs that should have turned on the instant when the captain pressed his override button and that indicate which sidestick has priority.

The above leads to the conclusion that crew did not observe the dual input procedure.

The results of these actions as they affected both pitch and bank are analyzed next. Along these lines, it is worth remembering that, as noted previously, when dual inputs are provided to the sidesticks, the system interprets the command to be executed as the arithmetic sum of both signals.

The pitch commands were characterized by:

- An initial nose up input.
- Followed by numerous inputs in both directions.
- The sidestick inputs were practically opposite (one side commanding the nose up while the other commanded it down), though the overall effect was to provide a nose down command.
- The arithmetic sum of the signals resulted in a smoother signal than either of the individual commands, which served to dampen the dual input effect.
- There were no significant changes in SPD-MACH, pitch or angle of attack.
- As a consequence of the predominant nose-down command, there was an initial ascent of 300 ft to 32,700 ft, followed by a descent of 2,400 ft to 30,300 ft.

Banking commands:

- These were clearly in agreement.
- There were seven simultaneous inputs in both directions.
- In the first four inputs, both sidesticks were deflected to the maximum. While the dual input effect arithmetically sums the commands from both sidesticks, the resulting signal can never be greater than that provided by the maximum deflection of one, meaning that during these four initial actions, the fact that both pilots were providing simultaneous inputs had no effect.
- During the three successive inputs, neither sidestick reached its maximum deflection but the arithmetic sum did, which could have caused an over correction.

Yaw commands:

The DFDR recorded several inputs to one of the left pedals, though the system is such that no determination can be made as to which pedal was pressed, the captain's or the copilot's, since both pedals are supportive. In either case, the inputs recorded were all in the same direction, to the left, and reached a maximum value of 9°, resulting in a maximum rudder displacement of 5.2°.

The force required to produce this pedal displacement is 13 daN, which is approximately equivalent to 40% of the force needed to displace the pedal the entire length of its travel.

Effect of actions taken

Finally, the effect of the crew's inputs to the flight controls on the aircraft's behavior will be analyzed.

The maximum sidestick inputs to either side induced the aircraft to suffer banking movements.

As for the pitch commands, the fact that the crew's inputs were largely in opposing directions meant that the resulting movement was smooth, and thus had little effect on the pitch of the aircraft.

2.2.2. *Throttle inputs*

The captain retarded the throttles to almost the idle position, keeping the autothrust on, though it was subsequently disengaged.

The procedure for flying in severe turbulence specifies that the engine thrust should not be modified unless the airspeed is significantly altered, and that the autothrust should only be disengaged if there are excessive changes in engine thrust. Neither circumstance was present in this incident.

When the turbulence started, the aircraft's speed was 0.78M. The recommended speed for their situation was 0.76M, so only a slight adjustment to the throttles had been necessary.

The crew's throttle inputs resulted in the aircraft's speed decreasing to 0.74M, which is below the 0.76M recommended for flying in turbulent conditions.

It may be concluded, therefore, that the crew did not strictly adhere to the severe turbulence procedure.

2.2.3. *Crew activity*

Although it is appreciated that the copilot had an intense and continued activity, with values near the limits of monthly activity, even with some excess of activity in a few days before the incident, the existence of broad rest periods in the past closest to the incident suggests that fatigue was not a factor in this case.

2.3. Maintenance aspects

The aircraft's maintenance manual includes maximum vertical and lateral acceleration values which, if exceeded, require an inspection of the aircraft. There are no values above those already noted which, if exceeded, would require the manufacturer's direct supervision and intervention before the aircraft can be returned to service.

The suitability of establishing such limits has already been manifested in the NTSB reports listed in Section 1.8.1, which gave rise to several safety recommendations and which resulted in the FAA putting in place a process for their implementation that would serve to fully satisfy the safety requirements involving maintenance aspects.

2.4. Training

The crew's actions revealed that the dual input and severe turbulence procedures were not strictly observed even though in the months leading up to the incident, both pilots had received A-320 refresher training and training on crew resource management (CRM).

3. CONCLUSION

3.1. Findings

The Airbus A320-300 aircraft, while flying between Barcelona and Santiago de Compostela on flight VLG1190, encountered strong turbulence as it climbed through FL325 at a speed of 0.78M, that caused it to bank to the right at a 40° angle.

At that time the aircraft was climbing through FL325 to FL370. Its weight was 61T and it was in a clean configuration. The autopilot (AP2) was engaged in CLIMB/NAV mode and the autothrottle was engaged and active. The CM2 was the PF.

The autopilot immediately attempted to counteract the increased bank angle, deflecting the ailerons to their maximum value of 8° at 250 kt. The vertical load factor, meanwhile, increased to 1.23 g.

Since the bank angle continued to increase, the crew reacted by moving their sidesticks, which disengaged the autopilot.

The CM1 reacted to the decreased vertical load factor by commanding a pitch up. Almost simultaneously, the CM2 was inputting the opposite command, namely pitch down, to his sidestick.

For 21 seconds, both pilots were simultaneously providing inputs to their sidesticks. This resulted at the start of the event in both pilots pushing their sidestick to the maximum in both lateral directions. During this time period there was also an input to the left pedal.

As a consequence of the external turbulence and of the crew's actions, the aircraft banked sharply, reaching maximum values of 33° left bank and 49° right bank. The pitch angle was also considerable and varied between 8.7° and -0.4°. The longitudinal and lateral load factors ranged from 1.69 g/–0.45 g and 0.47 g left and 0.32 g right.

After this, and as a result of the various pitch-down commands, the airplane started to descend. Also during this time the crew disengaged the autothrottle. Once the turbulence stopped, the crew re-engaged both the autothrottle and the autopilot. The aircraft attained the selected flight level (FL310) and continued without further incident to its destination.

The inspections prescribed in the event of excessive turbulence were conducted. No anomalies were detected. Also, and as a consequence of the high lateral acceleration values, additional inspections were conducted, the results of which were also satisfactory.

The analysis carried out after the flight concluded that no design load limits had been exceeded during the flight.

3.2. Causes

The turbulence was initiated by the wake of an Airbus A340-300 that was on the same airway, 10.13 NM ahead of the Vueling Airbus A320-200, and on the same course, flying toward point “Kuman” at FL330 and a ground speed of 464 kt. The extent of the turbulence was such that it could not be counteracted by the autopilot.

The actions carried out subsequently by the crew, simultaneous sidestick inputs, retarding the throttles, disconnecting the autothrust and, especially, stepping on the left pedal, were not in accordance with the aircraft’s flight procedures and could contribute to exacerbating the effects of the external turbulence.

4. SAFETY RECOMMENDATIONS

When an abnormal or emergency situation occurs during a flight, the crew must take immediate actions to neutralize it by following the proper procedures. In order to execute these actions quickly and accurately, the crew must carry them out "automatically". This is achieved through instruction and training.

The investigation into this incident revealed that the crew did not properly adhere to the procedures required by the situation. As a result, and in an effort to improve the safety of operations, the following safety recommendation is issued.

REC 03/11. It is recommended that the aircraft operator, Vueling, review and enhance its Airbus A-320 crew training programs so as to improve the crews' knowledge and application of aircraft procedures, in particular of these applied to dual sidestick inputs, flying in severe turbulence and rudder use.

REC 04/11. It is the recommended to the operator of the aircraft, Vueling, review and enhance its training programs in Crew Resources Management CRM.