Air Accident Investigation Unit Ireland

SYNOPTIC REPORT

SERIOUS INCIDENT
Boeing 737-8AS, EI-DPA
Faro, Portugal
24 October 2011

An Roinn Iompair Turasóireachta agus Spóirt
Department of Transport, Tourism and Sport

Foreword

This safety investigation is exclusively of a technical nature and the Final Report reflects the determination of the AAIU regarding the circumstances of this occurrence and its probable causes.

In accordance with the provisions of Annex 13[1] to the Convention on International Civil Aviation, Regulation (EU) No 996/2010[2] of the European Parliament and the Council, and Statutory Instrument No. 460 of 2009[3], safety investigations are in no case concerned with apportioning blame or liability. They are independent of, separate from and without prejudice to any judicial or administrative proceedings to apportion blame or liability. The sole objective of this safety investigation and Final Report is the prevention of accidents and incidents.

Accordingly, it is inappropriate that AAIU Reports should be used to assign fault or blame or determine liability, since neither the safety investigation nor the reporting process has been undertaken for that purpose.

Extracts from this Report may be published providing that the source is acknowledged, the material is accurately reproduced and that it is not used in a derogatory or misleading context.

[1] **ICAO Annex 13**: International Civil Aviation Organization, Annex 13 to the Convention on International Civil Aviation, Air Accident and Incident Investigation.

[2] **Regulation (EU) No 996/2010** of the European Parliament and of the Council of 20 October 2010 on the investigation and prevention of accidents and incidents in civil aviation.

[3] **SI 460 of 2009**: Air Navigation (Notification and Investigation of Accidents, Serious Incidents and Incidents) Regulations 2009.

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In accordance with Annex 13 to the Convention on International Civil Aviation, Regulation (EU) No. 996/2010 and the provisions of S.I. No. 460 of 2009, the Chief Inspector of Air Accidents, on 25 October 2011, appointed Mr Thomas Moloney as the Investigator-in-Charge to carry out an Investigation into this Serious Incident and prepare a Report.

Aircraft Type and Registration:	Boeing 737-8AS, EI-DPA
No. and Type of Engines:	2 x CFM56-7B26
Aircraft Serial Number:	33602
Year of Manufacture:	2006
Date and Time (UTC[4]):	24 October 2011 @ 17.06 hrs
Location:	Faro Airport, Portugal (LPFR)
Type of Operation:	Commercial Air Transport/Scheduled Passenger
Persons on Board:	Crew 6 Passengers 145
Injuries:	Crew Nil Passengers Nil
Nature of Damage:	Significant
Commander's Licence:	ATPL[5] issued by Irish Aviation Authority (IAA)
Commander's Details:	Male, aged 29 years
Commander's Flying Experience:	4,366 hours of which 4,088 were on type
Notification Source:	Aviation Safety Report Filed by the Operator
Information Source:	AAIU Investigation

[4] **UTC**: Universal Coordinated Time, add one hour for local time.
[5] **ATPL:** Air Transport Pilot Licence.

SYNOPSIS

During the early hours of 24 October 2011, LPFR was struck by a rare meteorological phenomenon known as a microburst[6] associated with a supercell[7], during which wind speeds of up to 84.9 kts were recorded at a weather station at LPFR. EI-DPA, which was parked overnight on the ramp, jumped its chocks and its nose moved approximately 5 metres (m) to the left. During the event, the aircraft sustained significant damage to its rudder system due to the effects of the wind gusts on the rudder control surface. The damage was not visible from the ground and was not detected during the subsequent Ramp-1 Check (**Section 1.9.2**) and pre-flight checks. Later that day, the aircraft departed on its first scheduled flight and the Flight Crew encountered significant control difficulties immediately after take-off due to the damaged rudder system. The Flight Crew dealt with the control issues and returned to LPFR where they landed safely approximately 28 minutes after take-off.

NOTIFICATION

The occurrence was notified by the Operator to the AAIU through the IAA's Safety Occurrence Tracking System (SOTS). The AAIU passed the report on to the Portuguese aviation safety investigation authority, the GPIAA[8], as State of Occurrence. The GPIAA decided to delegate the Investigation to Ireland as State of Registry and State of the Operator.

1. FACTUAL INFORMATION

1.1 History of the Flight

EI-DPA had been parked overnight on the ramp at LPFR on the 23/24 October 2011, along with a number of other aircraft owned by the Operator. During that night at approximately 04.00 hrs, a violent storm struck the area of LPFR and caused substantial structural damage to some airport buildings. It was reported that, during the storm, EI-DPA had jumped its chocks and pivoted nose left with the nose landing gear moving approximately 5 m from its original position.

The Technical Log for the aircraft shows that it was released to service at 05.00 hrs on the 24 October 2011 after a Ramp-1 Check. The Technical Log contained no specific reference to the overnight winds or to the fact that the aircraft had jumped its chocks and moved.

It was also reported that several other aircraft owned by the Operator had jumped their chocks and moved during the storm. No associated damage was subsequently reported on those aircraft.

The first flight of the day for EI-DPA was a scheduled afternoon service from LPFR to Beauvais (LFOB), France. The Commander told the Investigation that he was aware of the overnight storm and that during his pre-departure walk-around he was extra vigilant for damage. The aircraft was parked on Stand 18 and was on a heading of approximately 010°.

[6] **Microburst:** A localised column of very rapidly descending air produced by Cumulonimbus (Cb).
[7] **Supercell:** A large slow-moving area of updraft and downdraft which causes violent thunderstorms, heavy hail, and tornadoes.
[8] **GPIAA:** *Gabinete de Prevenção e Investigação de Acidentes com Aeronaves*.

He stated that he found sand and grit in the bottom of the engines and some fibreglass insulation material that had blown into the back of the No. 1 engine and was sitting behind the N1 fan. He requested an engineer and they agreed that they would wait for the passengers to board and that the engineer would then remove the material. The Commander stated that the engineer had told him that the aircraft had been checked. Later the engineer confirmed to the Commander that the material had been removed.

The weather in both LPFR and LFOB was good and the Commander opted for the First Officer (FO) to act as Pilot Flying (PF) for the first sector. The Commander stated that he mentioned to the FO to pay particular attention for an abnormal engine start. However, the two engine starts were normal. Before commencing their taxi, the Flight Crew carried out the standard flight control checks as part of the pre-departure checklist, with no anomalies identified. The Commander stated that the taxi out to the runway was normal.

The aircraft was cleared for take-off on Runway (RWY) 28 at 17.06 hrs and was passed a wind check of 310°/15 kts. The Commander stated that the initial take-off roll was normal. As the aircraft rotated, he observed that *“we were drifting slightly right of the centreline. At the same time we had almost full left aileron deflection. The FO mentioned that the aircraft didn’t feel right.”*

The Commander’s first thought was they had suffered an engine failure but all engine indications were normal. On the climb-out the FO demonstrated to the Commander how the aircraft wanted to roll to the right. The Commander stated *“the FO put in some left rudder trim but not enough to engage the autopilot.”* The Flight Crew retracted the flaps and continued to fly the Standard Instrument Departure (SID), approximately six miles straight ahead followed by a 90° right turn. The Flight Crew completed the after take-off checks and made the right turn onto a northerly heading. They decided to maintain an indicated airspeed of 220 kts. When the aircraft had completed the right turn, the FO added more left rudder trim and he then succeeded in engaging the autopilot. The Commander stated *“It took about eight units of left rudder trim to centralise the control column”*.

The aircraft had been cleared to climb to Flight Level (FL) 240 and the Flight Crew decided that they should level off at FL 120 and remain in the vicinity of LPFR. This was facilitated by ATC. The Commander consulted the Flight Controls section of the QRH[9]. He stated that the most relevant checklist was for jammed or restricted controls but he considered that their *“controls were neither jammed nor restricted, they were just very out of trim”* so the Flight Crew decided that there was no applicable checklist in the QRH.

They then used the Operator’s problem solving model (PIOSEE[10]) and decided that their best option was to return to LPFR. The Commander stated that, *“Once the aircraft had been trimmed it flew normally with the autopilot engaged. However we knew that an engine failure would require about five units of rudder trim and we had eight. We knew there had been high winds the night before which may have caused damage. Weather was good in Faro and it was an engineering base so we made the decision to return.”*

[9] **QRH:** Quick Reference Handbook.
[10] **PIOSEE:** Problem, Information, Options, Select, Execute, Evaluate.

The Commander briefed the Cabin Crew and made an announcement to the passengers. The Flight Crew planned for a normal flap 30 landing on RWY 28. The Commander stated that he regularly flew with the FO who was experienced. He knew his abilities and he was happy to allow him to conduct the approach and landing. They carried out a briefing on the possible threats that could occur during approach and landing.

The aircraft carried out an ILS[11] approach to RWY 28. The Commander stated that after completion of the pre-landing checklist, the FO had remarked, *"OK I'm just going to fly it in"* and *"It's not too bad at the moment actually".*

The Commander described the approach and landing as normal and the aircraft landed at 17.36 hrs. The aircraft taxied to the terminal building and, after it parked, engineering staff came on board for a briefing. After a short interval, the engineering staff told the Flight Crew that further checks on the aircraft would be needed and the passengers were disembarked.

1.2 Damage to Aircraft

Following EI-DPA's return to the ramp at LPFR, the Commander entered the following information in the Technical Log. *"Flight control check in before taxi checks normal. Normal taxi. At low speed t/o normal. As we accelerated past about 100 kts the amount of right* (sic) *rudder required to keep the aircraft straight increased significantly (wind only 300/15, runway 28). On rotation a large left aileron deflection required to keep the aircraft from banking. Rudder trim applied to minimise the bank and engage the autopilot. Approx 8 units of left rudder trim required. Returned to Faro. Normal landing."*

The Operator's engineering staff removed panels from the aircraft's vertical stabiliser to gain access to the areas of the Main and Standby rudder Power Control Units (PCUs), see **Figure No. 1**.

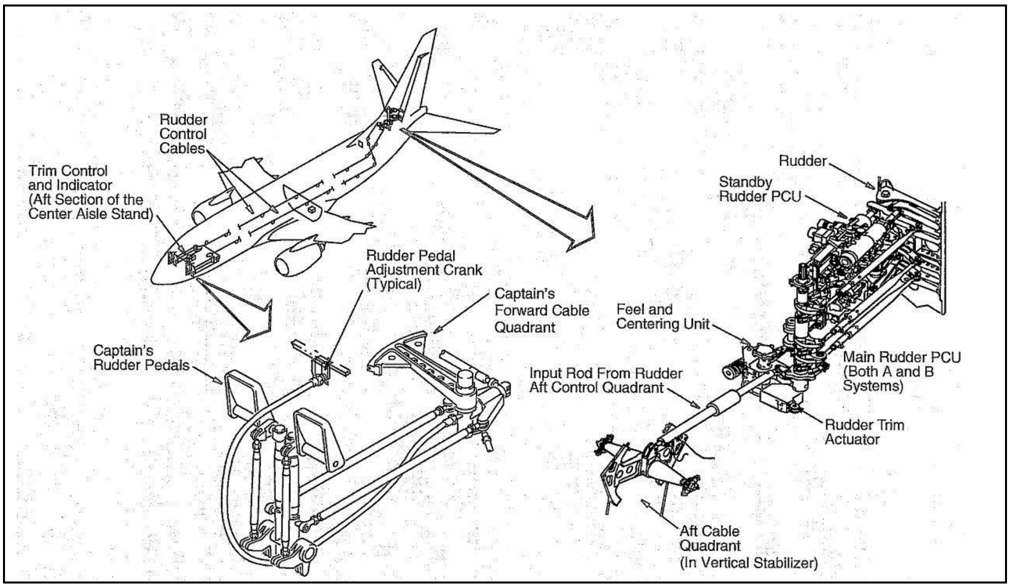

Figure No. 1: Rudder Trim and Control System (*Boeing*)

[11] **ILS:** Instrument Landing System

The support brackets for both PCUs were seen to have sustained damage, such as cracking, fracturing and displacement. The Operator provided photographs of the damaged areas to the Investigation and to the aircraft Manufacturer. The Manufacturer proposed that they would send an engineering team to LPFR to examine the damage and this was agreed with the Investigation and the Operator. The Investigation arranged for the examination to be overseen by an investigator from the GPIAA.

The Manufacturer's team carried out their examination of EI-DPA between November 16 and 18, 2011. When they removed panels from both sides of the vertical stabiliser, they found remnants of sheared fasteners together with broken pieces of the anti-rotational bushings from both rudder PCUs at the bottom of the bay containing the PCUs. These items were removed and packaged to be sent for laboratory examination.

The rudder was found to be moving freely but with more travel to the right than to the left. Its aerodynamic surface was clean and showed no signs of buckling or any other deformation. They found that at the tailstock[12] of the Standby PCU, the upper and lower flanges attached to the support brackets securing the forward part of the PCU were cracked, see **Photo No. 1**. A lug fitting, also part of the securing mechanism of the Standby PCU, was found to have pulled away from one of the support brackets. In addition, one of the brackets exhibited gaps where it had pulled away from the adjacent flange.

Photo No. 1: Damage to Standby PCU Support Bracket

[12] **Tailstock:** Part of the PCU actuator which is attached to the support structure of the aircraft.

At the Main PCU tailstock, four fasteners securing the left hand support bracket to the adjacent structure had sheared and the bracket had been displaced significantly forward and left, see **Photo No. 2.**

The right hand support bracket fasteners remained intact but the bracket itself was deformed. A gap was found to have developed between the lug fitting and the right hand support bracket.

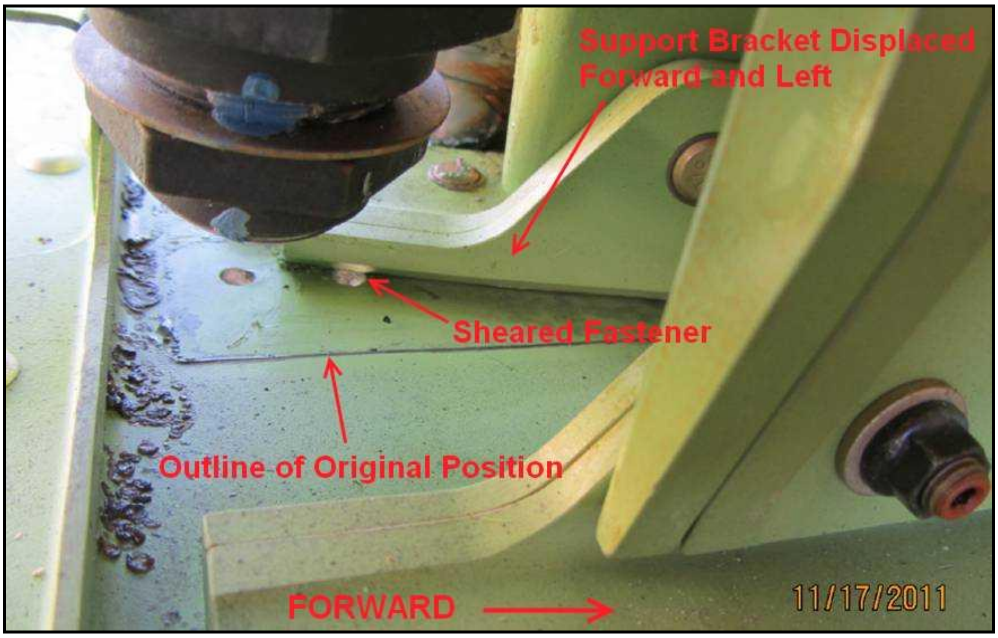

Photo No. 2: Displacement of Main PCU Support Bracket

The rudder is a single control surface manufactured from a graphite-based composite material, and it provides control of the aircraft around the yaw axis. It is attached to the trailing edge of the vertical stabiliser at a number of hinge points.

When the blade seals[13] were removed from the stabiliser, visual examination of the right side of the leading edge of the rudder revealed damage at various hinge points. The damage in the area of No. 2 hinge is shown in **Photo No. 3**. Similar damage was documented at hinges Nos. 5, 7, 8 and 9.

[13] **Blade seal:** A fairing attached to each side of the rear of the vertical stabiliser to seal the area between the rear of the stabiliser and the leading edge of the rudder.

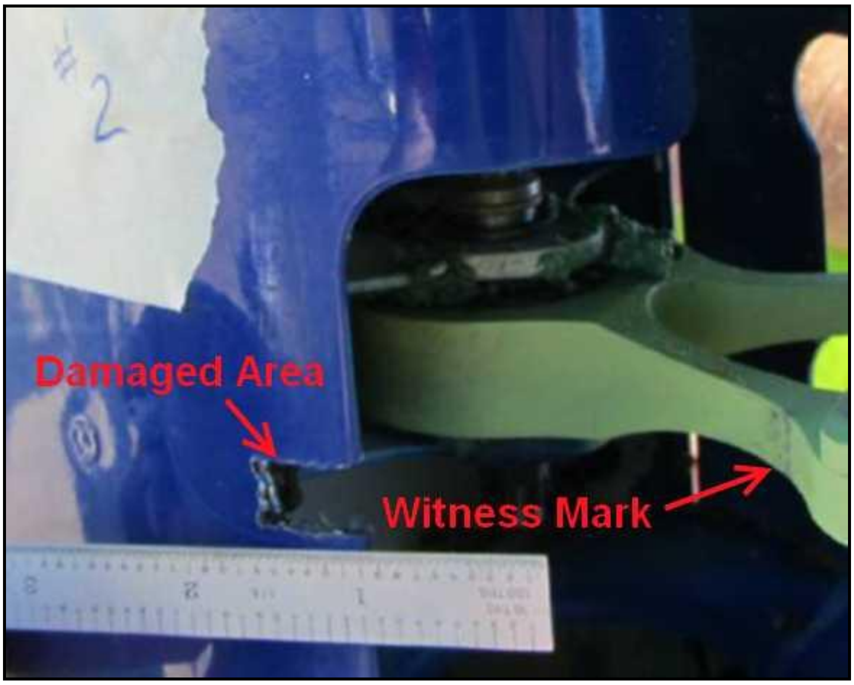

Photo No. 3: Damage to Rudder Leading Edge at Hinge No. 2

This damage exhibited evidence that the rudder had over-travelled with the trailing edge moving to the right. The skin of the rudder leading edge had come into contact with the hinge mechanism structure, which perforated the rudder skin leaving impact marks on the hinge mechanism. The GPIAA Investigator who oversaw the inspection stated that the damage in the area of the hinges could not be seen when the blade seals were in place, and in particular was not visible from the ground during what he termed a "*normal inspection*." He also reported that the hinges and balance panels were found to be in good condition.

Hydraulic power was turned on, the rudder pedals were centred and the rudder trim was set at zero. It was found that the offset between the rudder trailing edge and the index plate which is used as a reference point to centralise the rudder was 7 1/8 inches to the right (**Photo No. 4**).

Photo No. 4: Rudder Trailing Edge Offset from Neutral

The rudder trailing edge was aligned onto the index plate by the application of approximately 8 units of left rudder trim (**Photo No. 5**).

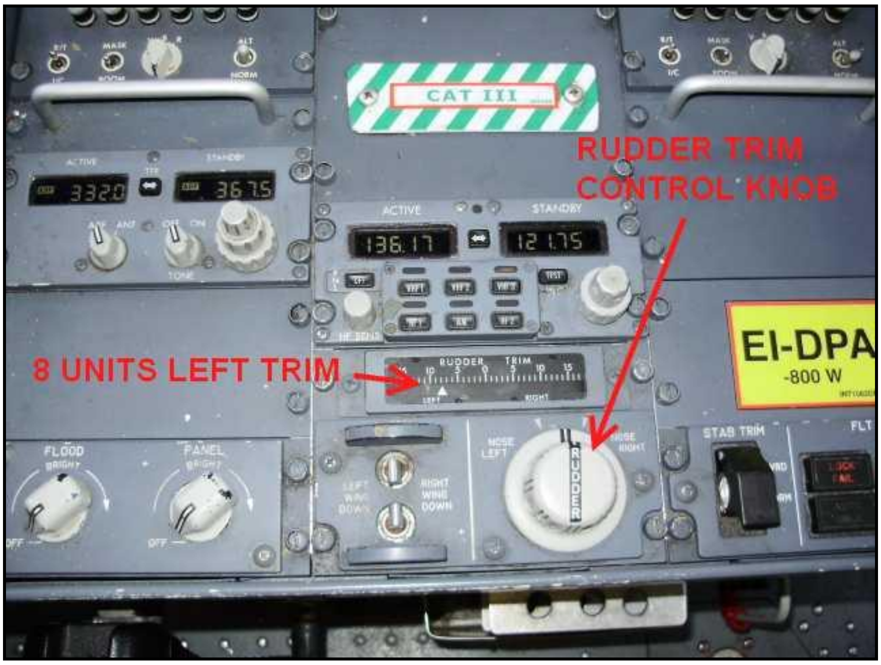

Photo No. 5: Rudder Trim with Rudder Centred

The team reported that they found no additional damage to the rudder system hardware and that there was no obvious external damage to either of the PCUs. They also inspected the elevator and aileron systems and in both cases reported that they found no collateral damage or anomalies. They also surveyed the control column forward stops and the rudder pedals forward stops, the stabiliser jack screw, the rudder pulleys and elevator pulleys and their associated control cables with no findings.

The nose landing gear was also inspected and the gear actuators were found to be leaking hydraulic fluid. The Operator reported that there had been no leaks prior to the wind event.

Subsequently, both the Main and Standby rudder PCUs were removed from EI-DPA and were forwarded to the Investigation for laboratory examination. The vertical stabiliser and rudder were removed from the aircraft and replacement units fitted. The damaged structural components were shipped to the AAIU and then forwarded to the National Transportation Safety Board (NTSB) for metallurgical examination, along with sheared fasteners and other damaged hardware.

1.3 Personnel Information

1.3.1 Commander

Personal Details:	Male, aged 29 years
Licence:	ATPL issued by IAA - Valid
Last Proficiency Check:	23 April 2011
Medical Certificate:	15 July 2012 - Valid

Total all types:	4,366 hours
Total all types P1:	1,366 hours
Total on type:	4,088 hours
Total on type P1:	1,212 hours
Last 90 days:	298 hours
Last 28 days:	100 hours
Last 24 hours:	8 hours

Duty Time up to Occurrence:	1 hour approx
Rest period prior to duty:	17 hours 30 mins

1.3.2 First Officer

Personal Details:	Male, aged 24 years
Licence:	ATPL issued by IAA - Valid
Last Proficiency Check:	21 June 2011
Medical Certificate:	31 January 2013 - Valid

Total all types:	2,815 hours
Total on type:	2,610 hours
Last 90 days:	278 hours
Last 28 days:	81 hours
Last 24 hours:	0 hours

Duty Time up to Occurrence:	1 hour approx
Rest period prior to duty:	24 hours

1.4 Aircraft Information

EI-DPA is a Boeing 737-800 aircraft, one of the Operator's large fleet of the type. On 23 October 2011, the day before the occurrence, a Ramp-1 Check was carried out on EI-DPA at LPFR in the early morning and the aircraft was released to service. It then completed two return flights from LPFR to UK airports followed by a return flight between LPFR and Porto, landing back at LPFR at 21.53 hrs. No defects were recorded on the Technical Log. On 24 October 2011, a Ramp-1 Check was signed off at 05.00 hrs and the aircraft was released to service.

The Boeing 737-800 aircraft is fitted with a single conventional hydraulically powered rudder without tabs. The rudder is controlled by displacing either set of rudder pedals in the cockpit.

Each set of rudder pedals is mechanically connected by cables to the input levers of the Main and Standby PCUs. The Main PCU consists of, *inter alia*, two independent input rods, two individual control valves, two bypass valves and two separate dual-concentric pistons, one for Hydraulic system A and one for Hydraulic system B. The independent Standby PCU is controlled by a separate input rod and control valve and is powered by the standby hydraulic system. The PCUs are located in the rear of the vertical stabiliser and are connected to the rudder. The PCUs are mounted inside the stabiliser using vertical support brackets which are attached by fasteners onto the flanges that are part of the stabiliser internal rib assemblies.

The rudder system does not incorporate a gust-lock. A gust damping function is provided by the bypass valves of the main PCU. There are flats machined into the valve spools which allow a metered flow of hydraulic fluid past an orifice to provide gust damping when there is no hydraulic pressure available (i.e. on the ground with engines not operating). Only the Main PCU has a gust damping capability.

The rudder trim control, which is located on the cockpit aisle stand, electrically positions the trim actuator on the rudder feel and centering unit. Movement of the trim actuator rotates the feel and centering unit which, in turn, provides an input to the PCU to move the rudder and thus adjust the rudder neutral position; the rudder pedals are displaced proportionately. The rudder trim indicator displays the rudder trim position in units.

Figure No. 2 illustrates the location of a PCU with respect to the support brackets while **Figure No. 3** illustrates how the support brackets are attached to the internal structure of the vertical stabiliser.

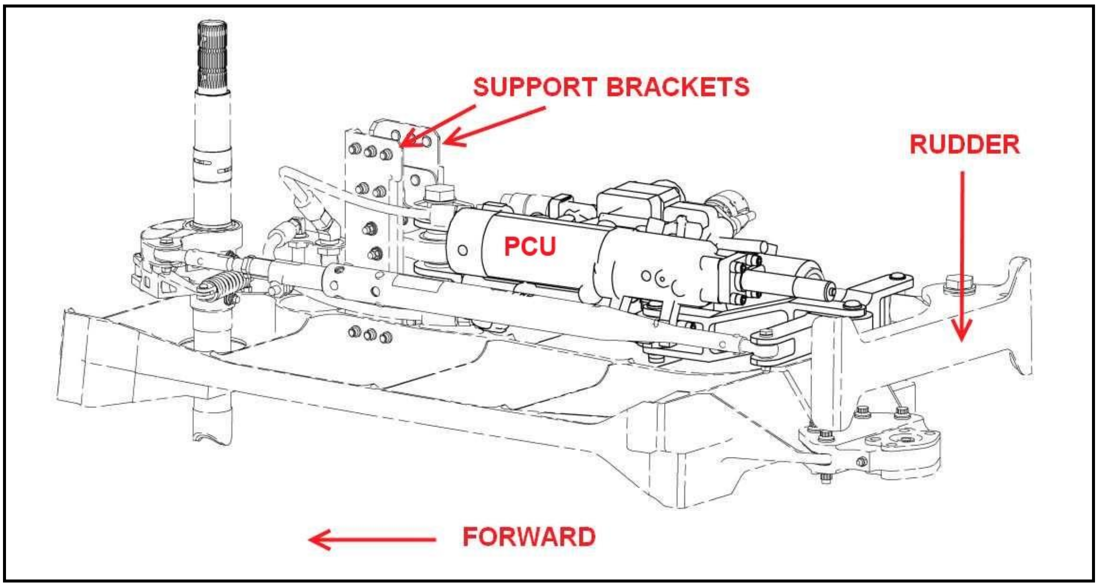

Figure No. 2: Standby PCU with Support Brackets *(Boeing)*

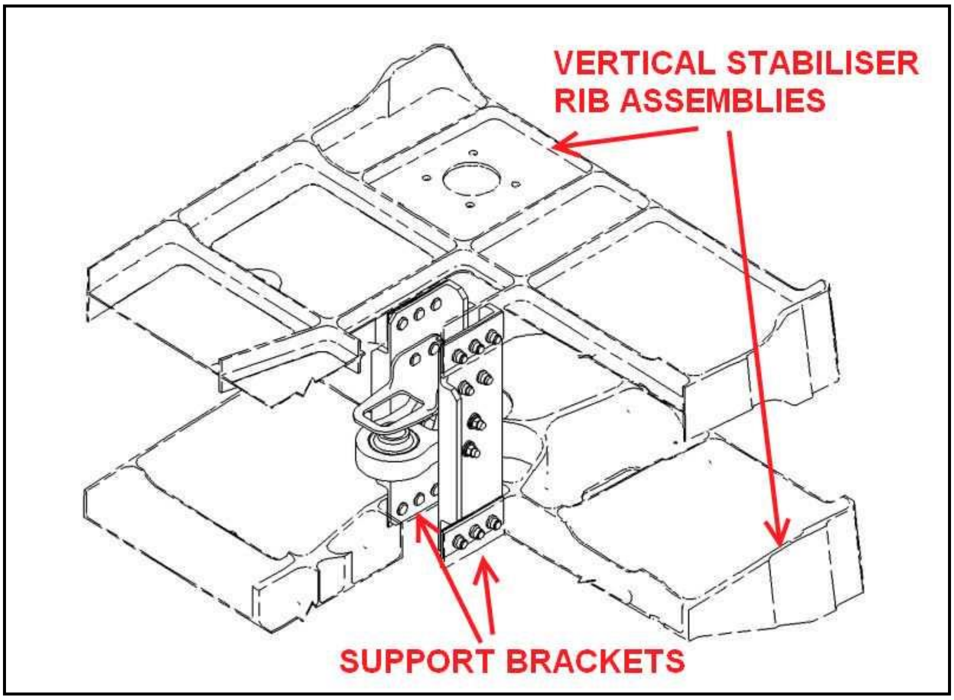

Figure No. 3: Standby PCU Support Brackets and Rib Assemblies *(Boeing)*

1.5 Laboratory Examination of Components

1.5.1 Rudder Power Control Units (PCUs)

The two PCUs from EI-DPA were shipped via the NTSB to the premises of the Original Equipment Manufacturer (OEM) in the United States. The two crates containing the PCUs were opened in the presence of an NTSB inspector representing the Investigation and examinations of the two units were carried out under his supervision.

The Main PCU was part number (p/n) 419300, serial number (s/n) 01914. Exterior inspection revealed a small impact scar/witness mark on the fastener located on the tail stock mounting tang. Extruded bonding material was observed at seven individual locations along the seam of one tang of the tailstock. An OEM technician stated that this was frequently observed on PCUs that have been in service. The PCU was subjected to the acceptance test protocol as outlined and documented in TDR 27-21-09 Rev L. No discrepancies were noted.

The Standby PCU was p/n 1001, s/n 2823. No external damage or witness marks were noted on inspection. The PCU was subjected to the acceptance test protocol as outlined and documented in TDR 27-20-70 Rev E. No discrepancies were noted.

A summary of the findings of the examinations of the Main and Standby PCUs is included at **Appendix A.**

1.5.2 PCU Tailstock Attach Hardware

The Investigation requested the NTSB to perform a metallurgical examination of the damaged PCU tailstock attach hardware, consisting of the Main PCU attachment bolts, the Standby PCU attachment bolts and the upper and lower trailing edge ribs. These items were crated and shipped to the NTSB Laboratories in Washington DC.

Examination of the Main PCU tailstock attach hardware revealed that the four left hand lower support bracket attachment bolts were all sheared. The right hand lower bracket attachment bolts appeared to be intact.

Examination of the Standby PCU tailstock attach hardware revealed that the brackets exhibited deformation, fractures and overload shear. Several of the attachment holes were elongated.

Examination of the main trailing edge hinge ribs revealed that both the upper and lower ribs had mating damage consistent with that noted for the Main and Standby PCU tailstocks' attach hardware. The NTSB characterised the overall damage as being consistent with an overload event.

A summary of the findings of the examinations of the PCU attach hardware is included at **Appendix B.** Photographs of some of the damaged hardware are included in **Appendix C.**

1.6 Meteorological Information

1.6.1 Portuguese Meteorological Report

The GPIAA provided the Investigation with a copy of a report on the extreme wind event, produced by the *Instituto de Meteorologia* of the Portuguese Ministry of Education and Science. The Investigation made arrangements to translate the report from Portuguese into English.

Photo No. 5, which is reproduced from the report, shows the location of four weather stations on LPFR airfield. Station EMA is located between RWY 28/10 and the parking area and there are three stations along the runway, SIO_10, SIO_MID and SIO_28, all of which are referenced in the report. The blue arrowed lines annotated with UTC times represent the maximum wind vectors at the four stations, which were recorded at the noted times. The vector marked 45 m/s in the upper left of **Photo No. 5** is provided for scaling purposes. The location of Stand 18 where EI-DPA was parked overnight is also shown for reference.

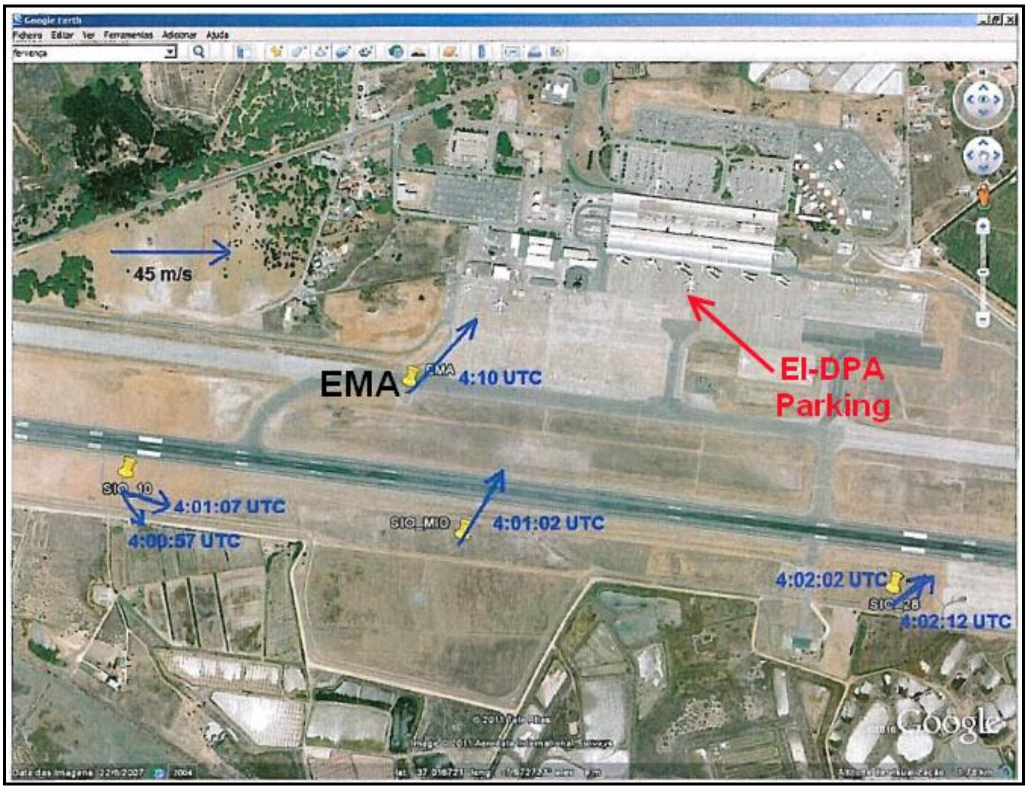

Photo No. 5: Maximum wind vectors at LPFR (*Google Maps*).

A translation of the Conclusions section of the Portuguese report is as follows:

In the early morning of October 24, 2011, Faro Airport and the adjoining built-up area, located east and northeast of same, were struck by a phenomenon called a microburst, in direct association with a supercell whose path was established over the mentioned area, advancing from southwest to northeast. The microburst must have affected the levels close to the ground more significantly, during the period between 04.01 hrs and 04.03 hrs UTC, and its path of destruction must have covered an approximate distance of 3 km, between the western area of Faro Airport to the city, with a variable width not exceeding 500 m.

A detailed analysis of radar and surface observations available for the period and area of interest and the use of relevant conceptual models led to the conclusions that:

- *The supercell with which the strong wind phenomena was associated propagated over the area of interest with a mean ground-level speed of about 19.5 m/s* [37.9 kts] *and a direction of approximately 244°;*

- *The mean wind intensity measured at the Faro Airport Automatic Weather Station (EMA) was always greater than 10 m/s* [19.4 kts] *during the 30 minutes preceding the phenomena, even exceeding 15 m/s* [29.2 kts] *at 03.30 hrs UTC;*

- *The maximum instantaneous wind intensity measured at the Faro Airport Automatic Weather Station was always greater than 15 m/s* [29.2 kts] *during the 30 minutes preceding the phenomena, peaking at 43.7 m/s* [84.9 kts] *in the 04.10 hrs UTC observation;*

- *Amongst the various surface observations available for wind, the highest maximum instantaneous wind figures were recorded at the EMA (43.7 m/s* [84.9 kts] *with a direction of 219° probably at 04.01 hrs UTC) and SIO_MID (33.0 m/s* [64.1 kts] *with a direction of 210° at 04.01 hrs UTC);*

- *The wind gust front propagation over the instrumented area was confirmed; its propagation speed was consistent with that of the supercell and its orientation was similar to a line linking the EMA and SIO_MID;*

- *The direction followed by the most intense flow of the microburst, when it propagated over the surface, was determined by the supercell movement in relation to the ground and the intensity of this movement was decisive for inducing the wind speed reached at ground level;*

- *The various observations available showed a match with the conceptual model adopted to explain the phenomena;*

- *Since the flow associated with the microburst, in addition to being extremely turbulent, might present non-horizontal components in certain areas, the possibility that the maximum instantaneous wind measured in this case could cause a default estimation of non-vertical flows that may have affected the area of interest should not be ruled out.*

The report states that it was possible to diagnose the presence of a supercell propagating over the airport area during the period of interest using weather radar observations. It also states, "*In this particular case, the supercell was a structure with significant evidence of a mesocyclone*[14] *presence. This component, which is essential for diagnosing a supercell and reveals a sustained updraft rotation, became particularly visible in the 03.56 hrs UTC and 04.06 hrs UTC observations, either for the life cycle which the supercell was in, or for its proximity to the L/CC radar station during that period.*"

The report goes on to state that, "*In a linear interpolation of the successive positions of the structure, referenced by the mesocyclone core, for a period between 03.36 hrs UTC and 04.06 hrs UTC, an approximate figure of 19.5 m/s* [37.9 kts] *was obtained for the mean supercell ground-level speed, whose advection direction was around 244°.… It is evident that the supercell mesocyclone core passed slightly to the northeast of the EMA, at around 1 km from the station*.

1.6.2 Forecast Meteorological Conditions

The following Terminal Aerodrome Forecasts (TAFs) were issued for LPFR at 17.00 hrs and 23.00 hrs on the 23 October 2011.

[14] **Mesocyclone:** A rapidly rotating air mass within a thunderstorm that often gives rise to a tornado.

```
TAF LPFR 231700Z 2318/2418 22023KT 9999 BKN015
  TEMPO 2322/2406 22028G38KT 2000 RADZ BR BKN010
  PROB30 TEMPO 2402/2406 22035G50KT 1000 +TSRA SCT004 BKN008
   SCT018CB
  BECMG 2406/2408 31012KT SCT018=

TAF LPFR 232300Z 2400/2424 22020G30KT 6000 RA SCT008 BKN015
  TEMPO 2400/2406 22028G38KT 3000 RADZ BR SCT005 BKN010
   PROB30
  TEMPO 2402/2406 22035G45KT 1500 +RA SCT003 BKN006 SCT018CB
   BECMG 2406/2408 31012KT SCT018=
```

The TAF issued at 17.00 hrs forecast that, temporarily between 22.00 hrs on the 23 October and 06.00 hrs on 24 October, the wind would be 220°/28 kts gusting to 38 kts with rain, drizzle and mist. This TAF also forecast that temporarily between 02.00 hrs and 06.00 hrs, there was a 30% probability that the wind would be 220°/35 kts gusting to 50 kts with thunderstorms and heavy rain.

The TAF issued at 23.00 hrs forecast that, temporarily between 00.00 hrs and 06.00 hrs on the 24 October, the wind would be 220°/28 kts gusting to 38 kts with rain, drizzle and mist. This TAF also forecast that temporarily between 02.00 hrs and 06.00 hrs, there was a 30% probability that the wind would be 220°/35 kts gusting to 45 kts with heavy rain and scattered cumulonimbus cloud.

1.7 Flight Recorders

1.7.1 Digital Flight Data Recorder (DFDR)

The aircraft DFDR was downloaded by the Operator and a copy of the data was provided to the Investigation and to the aircraft Manufacturer.

Figure No. 4 illustrates control wheel position and relevant rudder data during the flight controls full-and-free check performed by the Flight Crew immediately prior to the flight preceding the occurrence flight. **Figure No. 5** illustrates similar data for the same check carried out on the occurrence flight.

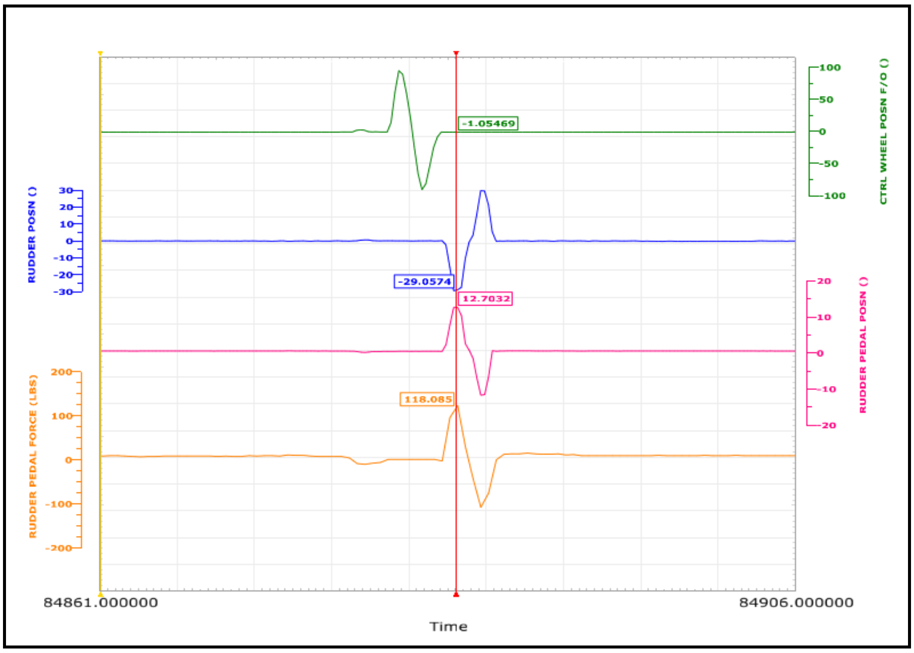

Figure No. 4: Rudder Data - Flight Prior to Occurrence Flight

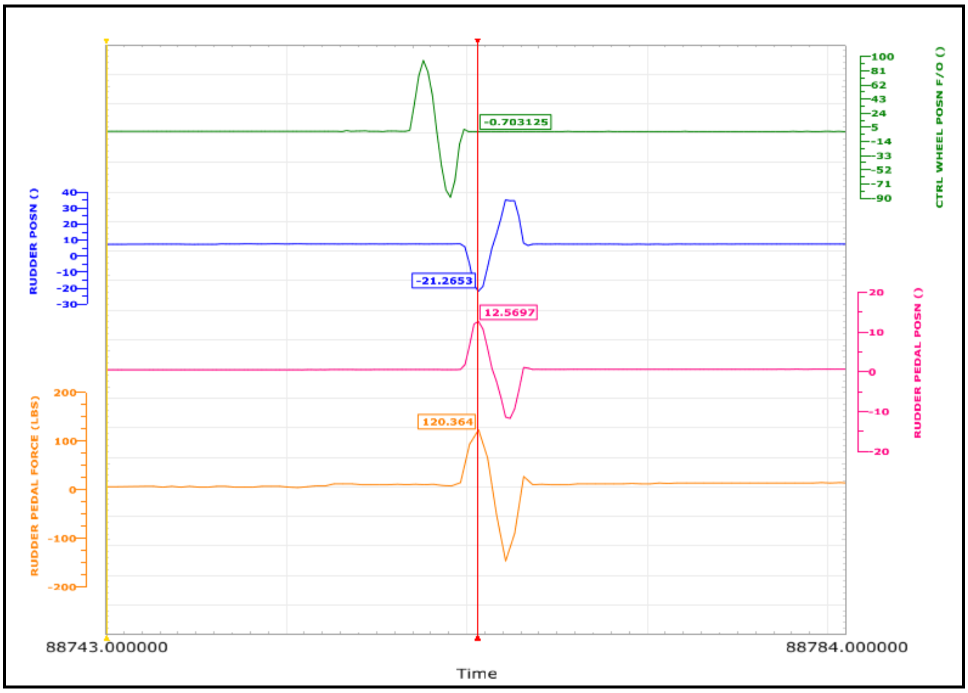

Figure No. 5: Rudder Data - Controls Check on Occurrence Flight

On the check carried out on the flight preceding the occurrence flight, the rudder movement was recorded between -29° (negative figures indicate trailing edge left) and +29.7° (trailing edge right). The rudder position was recorded at approximately 0° while the rudder pedals were at 0° and there was minimal force being applied to the pedals. On a similar check carried out immediately before the departure of the occurrence flight, the rudder movement was recorded between -21° and +35°.

The 'neutral' position was approximately +8° (trailing edge right) while the rudder pedals were at approximately 0° and there was minimal force being applied to the pedals. Note that this information was not available to the Flight Crew.

Figure No. 6 shows relevant recorded data for a period of 438 seconds[15] (7 mins 18 secs) immediately before and after the take-off on the occurrence flight. The uppermost trace shows the airspeed increasing from zero to approximately 220 knots as the aircraft accelerates along the runway, takes off and climbs away from the runway. The second trace from the top shows the ground/air parameter changing from ground (GND) to air (AIR) as the main landing gear lifts off the runway at take-off. The red vertical cursor is set at this point.

[15] **X Axis (Time)**: The x-axis is divided into ten main graduations, each representing a time interval of 43.8 seconds.

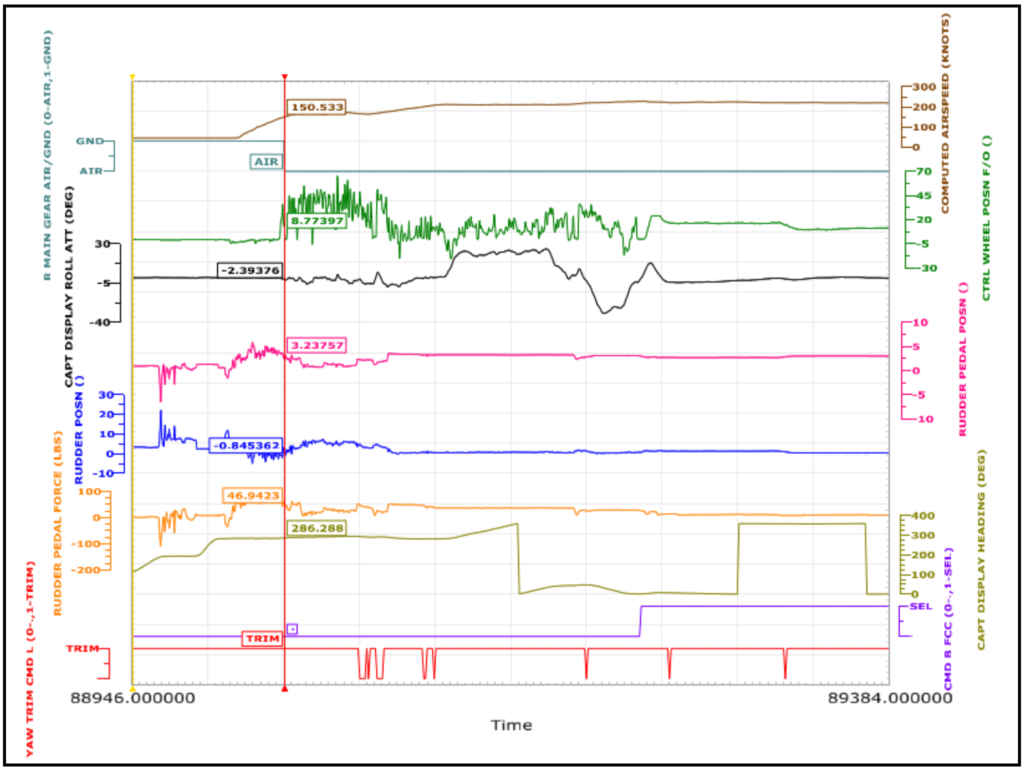

Figure No. 6: DFDR Parameters Before and After Take-off

The rudder remained at a recorded deflection of 8° right until the aircraft commenced its taxi to the take-off runway. During the taxi, the rudder pedals moved both left and right of the neutral 0° position. Simultaneously the rudder position moved left and right around a "central" deflection of approximately 8° to 10° trailing edge right. As the aircraft accelerated along the runway but before the ground/air parameter changed from GND to AIR, the rudder pedal position was recorded at values up to approximately 5° left. The rudder responded by moving to positions centred around 0°.

In the seconds immediately before and after the aircraft became airborne, the rudder pedals moved back towards the neutral 0° position and the rudder moved to a right deflection of up to 7°.

Approximately 45 seconds after take-off, the first of eight discrete inputs of left rudder trim was recorded. Shortly thereafter, the pedals position settled at approximately 3° left and the rudder moved to a deflection close to 0° where it remained until the landing. The autopilot was engaged approximately 3 minutes and 20 seconds after take-off, by which time six units of left rudder trim had been applied. The final input of left rudder trim was made approximately 4 minutes and 45 seconds after take-off.

The data shows that just as the aircraft became airborne, there was a significant movement of the control wheel position to the left. As the aircraft commenced its climb, the control wheel position was recorded at values up to 65° to the left. Recorded aileron deflection was consistent with control wheel position. The maximum recorded value of right hand aileron deflection was +13° (trailing edge down) while that for the left hand aileron was -14° (trailing edge up). The mechanical limits for aileron travel are +16° (trailing edge down) and -19° (trailing edge up) for each aileron.

During this time, the aircraft bank angle was recorded as being between 0° and 5° to the left. Approximately two minutes after take-off, the control wheel position moved to deflections between 0° and 20° to the left and the aircraft bank angle changed to values of approximately 20° to the right. The aircraft turned right onto a northerly heading. Approximately five minutes after take-off, with the control wheel position at values of approximately 10° left, the rudder pedals position at approximately 3° left with eight units of left rudder trim and the autopilot engaged, the aircraft bank angle settled around 0° or wings level. This remained the configuration, other than when the aircraft was making turns, until the autopilot was disengaged shortly before landing.

1.7.2 Cockpit Voice Recorder (CVR)

The CVR was forwarded by the Operator to the AAIU premises in Dublin, where it was downloaded in the AAIU laboratory. The CVR recording was of good quality and provided data from approximately 40 minutes prior to take-off until approximately 55 minutes after landing, at which time the Commander pulled the CVR circuit breaker (CB).

During the pre-start checklist, the Commander called, *inter alia*, *"Surfaces and controls"* to which the FO responded *"Checked"* and also *"Hydraulics"* to which the FO responded *"Normal"*. The Flight Crew also discussed the fact that some flights from LPFR had been cancelled that morning and that there were only four boarding gates available which was causing *"chaos"*.

During the engine starts, the Commander instructed the FO to *"keep a good eye on this"* as he thought that some extraneous material may have entered the engines the previous night. Between engine start and commencement of taxi to the runway, the CVR recorded a flight control check being conducted. The Flight Crew briefly discussed storm damage to the airport terminal building. In the before taxi checklist one of the items called by the FO was *"Flight controls"* with the response *"Check"* from the Commander.

The aircraft was cleared for take-off on RWY 28 with a wind check of 310°/15 kts. The Flight Crew completed the before take-off checklist. **Table No. 1** contains a transcript of portions of the CVR data recorded immediately following take-off, which are relevant to the occurrence. The timings listed in the left hand column are referenced to take-off thrust being set.

Time Reference (Min:Sec)	Source	CVR Transcript
00:41	FO	*Serious amount of rudder trim on that there*
00:50	FO	*Look how much aileron I need there*
00:52	Commander	*Yeah*
00:55	FO	*Is it ok the trim there*
00:56	Commander	*Yeah*
00:58	FO	*Something's seriously wrong with this*
01:20	FO	*Look at that look at it rolling*

Table No. 1: CVR Transcript

The Flight Crew then carried out the after take-off checks. The FO said that he would try to get some additional rudder trim in although there was quite a lot in already. He continued that the aircraft was *"flying ok"* other than the rudder issue. They decided to limit their airspeed to 220 kts and at time reference 03 mins 55 secs the FO said that he had successfully engaged the autopilot. They also decided to request ATC that they would level off the aircraft at FL 120.

They re-checked that their trimming action was in the correct sense and the Commander said that an engine failure required about five units of rudder trim. The FO responded that he had felt it on the runway but that the aircraft was not unsafe to fly.

They then discussed the situation and their options. They decided not to get too far away from LPFR. They consulted the flight controls section of the QRH[16] and in particular the section dealing with *"Flight controls jammed or restricted in roll, pitch or yaw".*

The Commander commented that what worried him was the previous night's wind. The crew discussed their options and decided that the best course of action was a return to Faro.

The Flight Crew requested vectors from ATC to keep them in the area of LPFR while they prepared for an approach. The Commander delivered a formal NITS[17] briefing to the No. 1 (most senior) Cabin Crew member and also made an announcement to the passengers that they would return to Faro due to a technical problem.

The Flight Crew then prepared for an approach to RWY 28. They decided to use *"Flaps 30"* in order to reduce drag and thus the degree of rudder required. The FO said that if the rudder issue became excessive on the approach that they would execute a go around and they could make another approach with less flap. The Commander, reverting to the QRH, stated *"Flight controls jammed or restricted they're not really…just severely out of trim".*

At time reference 22 mins 05 secs, the Commander informed ATC that they were ready for the approach. At 26 mins 35 secs, as the aircraft was on final approach to land, the FO stated *"I'm just going to fly it in….it's not too bad at the moment actually."* The aircraft landed at time reference 28 mins 55 secs.

As the aircraft taxied to the ramp, the Flight Crew discussed the occurrence further. The FO felt that movement of the aircraft during the previous night's storm may have been a factor. He said that it was only when the airspeed reached about 110 kts that he could feel the aircraft's abnormal behaviour. The Commander responded that he had not seen anything abnormal during the taxi out to the runway and that he had noticed the unusual amount of aileron required to correct the flight path during and after the take-off.

After the aircraft parked, a person came on board the aircraft to discuss the occurrence with the Flight Crew. During the conversation the FO described how whenever he released the control column, the aircraft went into a quite aggressive roll to the right.

[16] **QRH:** Quick Reference Handbook
[17] **NITS:** A briefing dealing with Nature (of the issue), Intention, Time and Special Instructions

Later the FO was discussing the event with another visitor to the flight deck. The FO asked whether the visitor had seen the aircraft which had moved during the overnight storm. The visitor replied that in his experience he had never previously seen an aircraft move. The FO asked, *"Did you tow them all back to…"* and the other person responded, *"Pretty much that's what happened. It was a nightmare here, the whole taxiway was covered in glass up to Stand 24, the tower blew out."*

1.8 Aircraft Type Certification Requirements

Part 25 of U.S. Federal Aviation Regulations (FARs) prescribes airworthiness standards for the issue of type certificates, and changes to those certificates, for transport category aircraft designed and manufactured in the United States, including the Boeing 737-800.

FAR 25.415 prescribes the standards for "*Ground gust conditions*". It sets out the requirements to which *"The control system must be designed…for control surface loads due to ground gusts and taxiing downwind"*.

The Federal Aviation Administration (FAA) informed the Investigation that the certification basis of the Boeing 737-800 included FAR 25.415 at Amendment 25-72 dated 20 August 1990. This Amendment set a maximum design wind speed of 88 ft/sec (52 kts). Amendment 25-91, which became effective on 29 July 1997, increased the design wind speed to 65 kts. The FAA stated that *"The maximum design wind speed was originally set at 88 feet per second (52 knots) under the presumption that higher speeds were predictable storm conditions and the aircraft owner could take additional precautions beyond engaging the standard gust locks. Amendment 25-91 incorporated a new requirement, § 25.519, for jacking and tie-down loads. This requirement was similar to the existing* [European] *Joint Aviation Requirement 25.519 and required consideration of the airplane in a moored or jacked condition in wind speeds up to 65 knots. In order to be consistent in the treatment of ground winds, the wind speed requirement in § 25.415 was increased to 65 knots at the same time."* The aircraft Manufacturer informed the Investigation that, although the FAR 25.415 design criterion for maximum wind speed applicable to the Boeing 737-800 was 88 ft/sec (52 kts), the aircraft type had in fact been shown to meet the higher 65 kts requirement as per FAR 25.415 Amendment 25-91.

The Investigation enquired from the FAA whether consideration has been given to an increase in the FAR 25.415 wind speed above 65 kts. The FAA responded, *"Yes. Several years ago, the Aviation Rulemaking Advisory Committee (ARAC), which includes participation by aircraft manufacturers and aviation authorities, reviewed § 25.415. ARAC recommended changes to § 25.415 and several related requirements, which have since been adopted by EASA[18] in CS-25[19].*

The FAA is in the process of making the same changes to § 25.415…. The ARAC considered increasing the speed requirement, but instead recommended additional dynamic factors be applied for those portions of the system and surfaces that could be affected by dynamic effects. This was because analysis indicates that the most significant contributor to the damage due to ground gust is the dynamic load effect."

[18] **EASA:** European Aviation Safety Agency
[19] **CS-25:** Certification Standards for Large Aeroplanes, issued by EASA; the European equivalent of FAR Part 25.

The FAA issued a Notice of Proposed Rulemaking (NPRM) on 28 May 2013 stating that adoption of the proposal would eliminate certain regulatory differences between the airworthiness standards of the FAA and EASA without affecting current industry design practices. This action would revise, *inter alia*, the ground gust design loads criteria.

In respect of FAR 25.415, the NPRM states the following. *"Section 25.415 currently requires that the flight control system be designed for loads due to ground gusts when parked or while taxiing. Section 25.415 is intended to protect the airplane flight control system and control surfaces from damage in these conditions. Although damage from ground gusts may not be an immediate hazard, the rule is intended to prevent damage to the control system that may not be detected before take-off.*

Several incidents have occurred in which airplanes sustained such undetected but severe damage to the flight control system due to the dynamic effects of ground gust conditions. The incidents occurred on airplanes with unpowered mechanical controls with significant flexibility between the control surface and the gust locking devices. This flexibility allows dynamic loads, greater than the static design gust loads, to occur.

This proposal would revise § 25.415 to stand alone in regard to the required multiplying factors and provide an additional multiplying factor to account for dynamic amplification. The design conditions would be set forth as two design cases—one with gust locks engaged and another as a taxiing case with the gust locks disengaged but controls restrained by the pilot and/or powered system. A 1.25 factor would apply to the design hinge moments to obtain static limit loads for the design of the control system. A further multiplying factor of 1.6 (total multiplying factor of 2.0) would be applied for those parts of the control system where dynamic effects could be significant. A factor lower than 1.6, but not less than 1.2, could be used if substantiated by a rational analysis. If a dynamic factor of 1.2 is accepted, the total multiplying factor would then be 1.2 × 1.25 = 1.5.

These changes would provide the greatest effect on mechanical, unpowered control systems which have shown the greatest susceptibility to damage. Powered control systems have hydraulic actuators that naturally protect them against dynamic loads due to ground gusts."

Although the 1.25 factor does not specifically appear in the current (Amendment 25-91) version of FAR 25.415, it does in fact already apply, through reference in two other associated FARs, 25.391 and 25.395. FAR 25.391 states, *"The control surfaces must be designed for the limit loads resulting from…..the ground gust conditions in §25.415…"* FAR 25.395 states, *"Longitudinal, lateral, directional, and drag control system and their supporting structures must be designed for loads corresponding to 125 percent* [1.25 factor] *of the computed hinge moments of the movable control surface in the conditions prescribed in §25.391."*

The proposed amendment to FAR 25.415 will include the 1.25 factor and the other associated FARs will be amended to remove the references to ground gusts. The NPRM states, "*We also propose to revise § 25.415 to reorganize and clarify the design conditions to be considered, and to identify the components and parts of the control system to which each of the conditions apply. As a result of the changes to §25.415, we propose removing the references to ground gusts in §§ 25.391 and 25.395(b). These actions would harmonize §§ 25.391, 25.395, and 25.415 with the corresponding EASA standards."*

The proposed FAR 25.415 set out in the NPRM states that *"(a) The flight control systems and surfaces must be designed for the limit loads generated when the aircraft is subjected to a horizontal 65 knots ground gust from any direction, while taxiing with the controls locked and unlocked and while parked with the controls locked."* The FAR states that, *"The control system and surface loads due to ground gust may be assumed to be static loads"* and it provides a formula for the computation of the hinge moments (H) for the ailerons, elevator and rudder, using 65 kts as the wind speed.

The proposed FAR continues, *"(d) The computed hinge moment…must be used to determine loads due to ground gust conditions for the control surface. A 1.25 factor on the computed hinge moments must be used in calculating limit control system loads.*

(e) Where control system flexibility is such that the rate of load application in the ground gust conditions might produce transient stresses appreciably higher than those corresponding to static loads, in the absence of a rational analysis, an additional factor of 1.6 must be applied to the control system loads of paragraph (d) of this section to obtain limit loads. If a rational analysis is used, the additional factor must not be less than 1.2.

(f) For the condition of the control locks engaged, the control surfaces, the control system locks, and the parts of the control systems (if any) between the surfaces and the locks must be designed to the resultant limit loads. Where control locks are not provided, then the control surfaces, the control system stops nearest the surfaces, and the parts of the control systems (if any) between the surfaces and the stops must be designed to the resultant limit loads. If the control system design is such as to allow any part of the control system to impact with the stops due to flexibility, then the resultant impact loads must be taken into account in deriving the limit loads due to ground gust."

1.9 Other Information

1.9.1 Aerodynamic Effects of Rudder

The primary effect of rudder is to provide directional control of an aircraft. An input of right rudder alters the shape of the vertical stabiliser/rudder aerofoil section, generating an aerodynamic force to the left at the aircraft tail. This sends the tail to the left and yaws the aircraft to the right about the normal axis through the aircraft centre of gravity. Rudder effectiveness increases with airspeed.

During the initial stages of flight (prior to the input of rudder trim), the sideslip induced by an offset rudder causes a rolling moment due to increased lift on the upwind wing (the left wing in this case). This is a static rolling moment and is the result of two factors, wing dihedral and wing sweep. These factors combine to increase the effective angle of attack on that wing thus increasing lift on that wing.

1.9.2 Pre-Flight Maintenance Actions

The aircraft Technical Log shows that a Ramp-1 Check was carried out on EI-DPA was signed off at 05.00 hrs on 24 October 2011. The Ramp-1 Check is performed by an engineer at intervals not exceeding 48 hours elapsed time. This requires a visual inspection of the aircraft with no panels removed and is carried out from the ground. It also incorporates a review of the Technical Log for defects, and a series of internal and external tasks including oil quantity checks, a visual check of the tyres for condition and wear, confirming proper inflation of the tyres, ensuring the aircraft is chocked and general visual inspections of the engine inlets and fan blades.

The Operator informed the Investigation that, on the day of the event, there was no maintenance check specific to the extreme wind event recorded in the Technical Log or on the central maintenance records system. There was no communication concerning the wind event between personnel at LPFR and the Operator's maintenance control between the time of the event and the departure of the aircraft.

1.9.3 Information from Aircraft Manufacturer

At the time of the occurrence, there was no specific maintenance check in the Aircraft Maintenance Manual (AMM) for such an extreme high wind event. The Manufacturer informed the Investigation that in October 2012, they published an amendment to the Boeing 737-600/700/800/900 AMM setting out a Conditional Inspection for an aircraft which has been subjected to an "Extreme High Wind Event". The document states that examples of such events are tornadoes and microbursts. It lists as examples of evidence of an extreme high wind event, situations where an aircraft has moved over its wheel chocks or where there are tyre skid marks on the ground where an aircraft was parked.

It also states, *"Extreme high winds from the side and aft direction while parked can cause damage to the aircraft flight control surfaces and flight control mechanisms internal to the wings, horizontal stabilizer and vertical stabilizer. It is possible that this damage will not be seen during a walk-around or during pre-flight checks."*

The Conditional Inspection includes examination of the external surfaces of flight control surfaces for damage, examination of actuator attach points and support structure and examination of the hinge attach structure of flight controls. It also sets out procedures for the examination of doors (if open at the time of the event) and landing gears.

1.9.4 Inspection Processes Following High-Load Events

In 2005 the Aerospace Industries Association (AIA) published AIA Publication 05-01, a Best Practices Guide on Inspection Processes following High Load Events. This guide is available at https://easa.europa.eu/essi/ecast/wp-content/uploads/2012/01/Best-Practices-Inspection-Processes-following-high-load-events.pdf.

The purpose of the document is to provide recommended practices that may be used by aircraft manufacturers when developing maintenance manuals, or by operators when adapting those manuals for their operation. Specifically, the document outlines recommended inspection processes following certain high load events. It was developed in response to a number of NTSB Safety Recommendations which addressed NTSB concerns that aircraft may encounter high load events during which structural damage occurs and the damage may not be found before the aircraft returns to service.

1.9.5 Intergovernmental Panel on Climate Change (IPCC) Report

The Investigation acknowledges that the extreme weather event which occurred at LPFR in October 2011 was rare. Nevertheless such events do occur from time to time and may be on the increase. The IPCC published a Report in March 2014 which identified key risks associated with climate change across sectors and regions. Among the risks, identified with high confidence, are *"systemic risks due to extreme weather events leading to breakdown of infrastructure networks and critical services such as electricity, water supply, and health and emergency services."*

This IPCC was established by the United Nations Environment Programme and the World Meteorological Organization in 1988 *"to provide the world with a clear scientific view on the current state of knowledge in climate change and its potential environmental and socio-economic impacts."* [20]

2. ANALYSIS

2.1 Meteorological Conditions

The Report produced by the Portuguese *Instituto de Meteorologia* contains factual evidence that LPFR and the surrounding area was struck by rare meteorological phenomena during the early hours of 24 October 2011. The Report concluded that a supercell propagated across the area of the airport along a heading of 244° and at a mean ground-level speed of 19.5 m/s (37.9 kts). A microburst, directly associated with the supercell, caused a path of destruction some 3 km in length and of variable width not exceeding 500 m, between the western area of LPFR and Faro city, particularly during the period between 04.01 hrs and 04.03 hrs.

The highest instantaneous wind speed observations recorded at the airport weather stations were made at 04.01 hrs. A wind speed of 43.7 m/s (84.9 kts) from a direction of 219° was recorded at EMA weather station, adjacent to the southwestern part of the ramp, while a wind speed of 33.0 m/s (64.1 kts) from a direction of 210° was recorded at SIO_MID, located just to the south of the mid-point of RWY 28/10.

The maximum instantaneous wind speeds recorded at the two other weather stations, which are located close to the touch-down points of RWYs 28 and 10, were considerably less. This illustrates the narrow and concentrated nature of the most intense part of the microburst. It is also quite possible that even higher wind speeds than the 43.7 m/s recorded at EMA were experienced at LPFR during the phenomenon.

[20] **Source:** IPCC Website

EI-DPA was parked on an approximately northerly heading on Stand 18 at LPFR when the microburst, approaching from the southwest, struck the airport. The orientation of the airport, with the ramp and runway to the south of the terminal buildings, is such that the ramp area is open to weather approaching from a southwesterly direction. It is probable that the severe wind gusts impacted on the left hand side and rear of the aircraft and as a consequence the rudder control surface moved rapidly, trailing edge to the right, which is consistent with the damage shown in **Photo No. 3** in **Section 1.2**.

The Boeing 737-800 is designed to meet the requirements of FAR 25.415 in respect of control surface loads due to ground gusts. A review of the 737-800 design found that the aircraft type meets the current FAR 25 requirement (as per Amendment 25-91) which sets a ground wind speed of 65 kts for calculation of control surface loads. In the subject case, it is likely that the aircraft and specifically the rudder surface and control system, was subjected to excessive loads due to ground wind speeds considerably greater than 65 kts.

The winds contained in the relevant TAFs had a maximum forecast value of gusts up to 50 kts. This wind speed was predicted with a 30% probability in the TAF issued at 17.00 hrs. The TAF issued at 23.00 hrs contained a maximum value of gusts up to 45 kts, again with a probability of 30%. Accordingly, the conditions actually experienced at LPFR during the passage of the supercell and the associated microburst were not forecast prior to the event.

2.2 Damage to Aircraft

The leading edge of the rudder was damaged by contact with the rudder attachment hinges at several hinge points. This damage demonstrated that the entire rudder control surface had over travelled to the right and its leading edge had come into contact with the hinges, which perforated the rudder skin at several locations. Otherwise the rudder surface was undamaged and exhibited no signs of buckling or deformation.

The rudder is connected to the two PCUs by pistons. On-site examination of these items revealed no obvious mechanical damage. The PCUs were shipped to the OEM's facilities and inspected under the oversight of the NTSB. Other than a small impact scar/witness mark on the fastener located on the tail stock mounting tang, the Main PCU was found to be in good condition and no discrepancies were noted during acceptance test protocols. Similarly, the Standby PCU passed its acceptance test procedure.

Significant damage was caused to the mounting brackets at both PCUs' tailstocks as well as to parts of the aircraft structure to which the brackets were attached. Four fasteners securing the left hand support bracket of the Main PCU had sheared allowing the support bracket to become significantly displaced forward and left. The Main PCU right hand support bracket fasteners were intact and the support bracket itself was not displaced but was permanently deformed. A gap was created between a lug fitting and the bracket.

At the Standby PCU tailstock, the upper and lower flanges attached to the support brackets were found to be cracked and gaps had appeared between one of the brackets and the flange to which it was attached.

It is probable that the control surface loads significantly exceeded the overload protection afforded by the maximum design gust damping provided by the Main PCU. This was due to the extreme gusts impacting the rudder from the left. Both PCUs remained undamaged by the loads being experienced through the system during the event. However, there was physical displacement of one of the Main PCU support brackets, where the attachment bolts had all sheared. The permanent deformation and gaps located at the other support bracket at its attachment points to the aircraft structure were caused by overload and over stress. Similarly, the fractures of the flanges attached to the Standby PCU support bracket and the deformation of the two brackets were caused by overload and overstress.

The physical movement of one of the PCU mounting brackets and the damage sustained by the others are likely to have resulted in the PCUs themselves being displaced with the consequence that the rudder “neutral” position was itself shifted, trailing edge to the right as shown in **Photo No. 4**.

Data from the DFDR illustrates how the characteristics of the rudder position changed between the flight immediately before the occurrence and the occurrence flight itself. The data shows that, on the preceding flight, when the rudder pedals’ position was at 0° and minimal force was being applied to the pedals, the rudder position was at 0° deflection, **Figure No. 4**. Also, the rudder movement was recorded between 29° trailing edge left and 29.7° trailing edge right, i.e. the rudder movement was approximately symmetrical around the 0° neutral point.

During the pre-flight check on the occurrence flight, with the rudder pedals’ position at 0° and minimal force being applied to the pedals, the rudder “neutral” position was at 8°, trailing edge right, **Figure No. 5**. The rudder movement was recorded between 21° trailing edge left and 35° trailing edge right when referenced to true neutral. This equates to an approximate rudder movement from 29° left to 27° right of the displaced rudder neutral point. Thus the overall movement of the rudder remained approximately symmetrical around the neutral point, but now displaced by about 8°, trailing edge right. However, the Flight Crew would not have been aware of this.

2.3 Operational Aspects

The initial effect of the trailing edge of the rudder being displaced to the right would have been a tendency for the aircraft tail to move to the left as the aircraft accelerated along the runway during its take-off roll. This was due to the altered shape of the vertical stabiliser/rudder aerofoil section, creating a lateral aerodynamic force to the left on the stabiliser. Rudder effectiveness increased with airspeed so as the aircraft accelerated along the runway, this lateral force increased.

This would have manifested itself to the Flight Crew as a tendency for the aircraft to drift to the right, which became more accentuated as the speed increased. The data shows that there was an increasing left rudder pedal input as the aircraft accelerated, which centralised the rudder and kept the aircraft straight along the runway.

As the aircraft became airborne, the rudder pedal position moved back towards 0° with the rudder itself again moving to the right. This rudder pedal movement is consistent with the normal centralisation of flight controls after take-off. The data shows an immediate and very significant input of left control wheel, with recorded values up to 65°. The PF required this opposite control wheel input to maintain the aircraft wings approximately level, in order to compensate for the roll to the right, which is the secondary effect of the rudder deflection to the right.

Approximately 45 seconds into the flight, the first of eight discrete inputs of left rudder trim was made. These inputs had the effect of repositioning the neutral point of the rudder trim actuator. Movement of the trim actuator rotated the feel and centering unit which in turn provided an input to the Main PCU to move the rudder to the left. The inputs of rudder trim would also have displaced the rudder pedals proportionately. This was reflected in the recorded value of 3° left rudder pedal position for the duration of the flight. The overall effect of the multiple inputs of rudder trim was to move the rudder deflection close to 0° where it remained until the end of the flight.

Approximately two minutes into the flight, the control wheel position moved to more central positions between 0° and 20° to the left, the bank angle changed to approximately 20° to the right and the aircraft made a controlled turn to the right onto a northerly heading. About five minutes after take-off, the control wheel was at an approximate deflection of 10° left. Eight units of left rudder trim had been input by the Flight Crew and the rudder pedal position was at 3° left. These control settings allowed the aircraft bank angle to be stabilised at approximately 0° or wings level and the rudder deflection to be settled at 0°.

With regard to the PF's decision to continue the take-off run and take-off, his subsequent conversations with the Commander indicate that the effects of the displaced rudder were becoming evident and required correction as the aircraft accelerated through 110 kts on the take-off run. He was able to compensate for the tendency of the aircraft to drift to the right on the runway through the use of opposite rudder pedal.

However, when the aircraft became airborne, the full effect of the rudder on the roll axis was evident and required immediate and sustained opposite control wheel input. His first thoughts were that an engine failure may have occurred. However, it quickly became apparent to the Flight Crew that the control difficulties were not related to asymmetric thrust.

Given the situation in which they found themselves once the aircraft became airborne, the issues were operationally well handled by the Flight Crew. They used the Operator's decision making tool to analyse the problems and to make the prudent decision to return to LPFR, which as their home base was familiar to them and also where they knew the weather to be good.

2.4 Pre-Flight Maintenance Actions

It is known that several aircraft including EI-DPA moved significantly during the weather event. The nose landing gear of EI-DPA reportedly jumped its chocks and pivoted approximately 5 m to the left. This indicates that the nose of the aircraft weather-cocked towards the extreme gusts coming from the left of the aircraft, as would be expected.

At the time there were no specific maintenance actions laid down in the AMM to deal with such an event. Thus, the only maintenance action carried out on EI-DPA on 24 October 2011 prior to its departure was the routine Ramp-1 Check. Furthermore, there was no consultation between personnel at LPFR and the Operator's maintenance control. The Investigation considers that there was a general lack of appreciation of the severity of the wind event and its potential effects on an aircraft.

As the Ramp-1 Check was primarily a visual inspection carried out from the ground, the damage to the rudder hinges was obscured by the blade seal and the internal structural damage in the areas of the PCU tailstocks was not visible. Similarly, the pre-flight inspection carried out by the Commander later in the day, did not reveal any of the damage that the aircraft had sustained. The Commander did identify a piece of fibreglass packing which had lodged behind the fan of one of the engines. It is considered likely that this was blown into the engine from the rear after the early morning Ramp-1 Check which was carried out while the winds were still relatively strong.

The Manufacturer's inspection team which arrived on-site about three weeks after the occurrence found that there was a hydraulic leak from the nose landing gear actuators. Such a leak was not noted on the Ramp-1 Check or the Commander's pre-flight walk-around. However, it is not possible to state whether this leak was caused by the occurrence or indeed how and when it developed.

The Investigation had concerns that, at the time of the occurrence, the AMM lacked guidance to maintenance personnel in carrying out supplementary checks on an aircraft which had been subjected to violent gusts while parked, as was the case with EI-DPA. However, in October 2012 the aircraft Manufacturer issued an amendment to the AMM providing guidance on a Conditional Inspection for Boeing 737-600/700/800/900 aircraft which had been subjected to an extreme high wind event. Therefore, the Investigation considers that a Safety Recommendation in this regard is not required.

2.5 Airworthiness Design Requirements

Transport category aircraft manufactured in the U.S.A. are certificated in accordance with the airworthiness standards set out in FARs. The requirements for the design of control systems in respect of loads on control surfaces caused by ground gusts are prescribed in FAR 25.415. The certification basis of the Boeing 737-800 included FAR 25.415 at Amendment 25-72, with its maximum design wind speed of 88 ft/sec (52 kts). However, the Manufacturer informed the Investigation that a review of the 737-800 design has shown that the aircraft type meets the ground gust requirements defined in the current Amendment 25-91 of FAR 25.415, which specifies a gust of 65 kts.

An NPRM to further amend FAR 25.415 was issued by the FAA in May 2013. The text of the proposed Amendment to FAR 25.415 includes a 1.25 multiplying factor on computed hinge moments which must be used in calculating limit control system loads. While this 1.25 factor does not appear in the current text of FAR 25.415, it already applies to the calculations of hinge moments through reference in two other associated FARs, 25.391 and 25.395.

The NPRM also includes an additional multiplying factor of between 1.2 and 1.6 to take account of those parts of a control system where dynamic effects caused by ground gusts could be significant. The 1.2 to 1.6 multiplying factor would provide the greatest effect on mechanical, unpowered control systems. However, this multiplying factor may not apply to a powered control system where the hydraulic actuators (e.g. PCUs), which provide gust damping, are attached directly to the control surface.

While the Investigation acknowledges that the meteorological event experienced at LPFR was very rare, nevertheless the undetected damage caused to the rudder system of EI-DPA was potentially very serious. The amendment to the AMM introducing a Conditional Inspection for Boeing 737-600/700/800/900 aircraft which have been subjected to an extreme high wind event mitigates the risks associated with such an occurrence. However, the Investigation considers that further study of the effects of extreme ground gusts on aircraft control systems would be beneficial in the context of FAR 25.415. This is particularly in light of the IPCC Report which sets out a *"key risk…identified with high confidence"* due to extreme weather events associated with climate change. A Safety Recommendation is issued to the Federal Aviation Administration in this regard.

3. CONCLUSIONS

(a) Findings

1. The area around LPFR was struck by the extreme meteorological phenomenon of a microburst at approximately 04.00 hrs on 24 October 2011.

2. Wind gusts of up to 84.9 kts from a direction of 219° were recorded at the EMA weather station, adjacent to the southwestern part of the LPFR ramp.

3. The maximum wind speed which was forecast in the two TAFs prior to the event was 50 kts.

4. EI-DPA was parked overnight on Stand 18 at LPFR on an approximate heading of 010° alongside several similar aircraft when the extreme weather event occurred.

5. EI-DPA jumped its chocks and its nose pivoted by 5 m to the left during the weather event.

6. The aircraft was repositioned onto its correct parking position following the event.

7. The Ramp-1 Check, which is primarily a visual check of the aircraft from the ground with no panels being removed, was signed off at 05.00 hrs on the 24 October 2011.

8. No other maintenance inspection was carried out at the time, nor was there any consultation with the Operator's maintenance control regarding the weather event.

9. The aircraft Commander carried out a pre-flight walk-round inspection of the aircraft, which he described as *"vigilant"* as he was aware of the overnight storm.

10. The damage was not visible from the ground and could not have been detected without the removal of panels.

11. At the time of the occurrence, the AMM contained no specific actions for inspection of an aircraft which had been subjected to extreme winds while parked. In 2012, an amendment to the AMM was issued by the Manufacturer which deals with such a scenario.

12. At the time, there was a general lack of appreciation of the severity of the weather event and its potential effects on an aircraft.

13. During the taxi to the runway for take-off, the Flight Crew carried out standard pre-flight checks of the flight controls including exercising the rudder pedals left and right, but no anomaly was detected.

14. FDR data shows that during these checks, the rudder moved between approximately 21° left and 35° right, which was approximately symmetrical around the displaced neutral point, being offset by about 8° to the right of centre.

15. The initial effects of the displaced rudder became evident to the PF as the aircraft accelerated through 110 kts. He compensated for the tendency of the aircraft to drift right on the runway by use of opposite rudder pedal.

16. Once the aircraft became airborne and the rudder pedals were centred, the full effect of the displaced rudder on the roll axis became evident. FDR data shows that the PF required up to approximately 65° of left control wheel input to keep the wings level during the initial climb away from the runway.

17. Following the input of six units of left rudder trim it was possible for the PF to engage the autopilot. A further two units of left rudder trim were input after engagement of the autopilot.

18. Following the application of eight units of rudder trim and with the control wheel at an angle of approximately 10° left, the aircraft flew with wings approximately level and the rudder in its central position.

19. The Flight Crew applied the Operator's problem solving model to the situation, following which they decided to return to LPFR where they landed safely approximately 28 minutes after take-off.

20. The leading edge of the rudder was damaged when it impacted the rudder attachment hinges at various hinge points during the weather event. This damage was not visible without removal of the blade seal.

21. The mounting brackets at the tailstocks of the Main and Standby PCUs suffered fractures, deformation and cracking damage. These items are located internally in the vertical stabiliser and were not visible from the ground during routine inspection.

22. Fasteners securing the left hand support bracket of the Main PCU sheared allowing the bracket to become displaced forward and left.

23. The physical damage in the area of the PCU tailstocks caused the rudder neutral position to be offset by approximately 8° to the right.

24. The Boeing 737-800 rudder system does not incorporate mechanical gust locks. A gust damping facility is provided by the Main PCU.

25. The damage was caused by the impact of extreme wind gusts on the rudder control surface. These gusts led to loads which exceeded the structural capability of the PCU supports.

26. The loads resulting from the wind gusts impacting on the rudder led to components in the rudder control system being subjected to mechanical overload and overstress.

27. The Boeing 737-800 flight controls meet the airworthiness standards laid down for ground gusts in FAR 25.415 at Amendment 25-91, which includes a wind speed of 65 kts.

28. It is probable that the wind gusts which impacted on EI-DPA considerably exceeded the wind speed of 65 kts laid down in FAR 25.415.

29. An NPRM was issued for the FAA in May 2013, proposing amendments to, *inter alia*, FAR 25.415. These amendments include additional multiplying factors for static limit loads and also for those parts of a control system where dynamic effects could be significant.

30. The proposed amendments to FAR 25.415 may have limited or no effect on certain powered control systems.

(b) Probable Cause

Undetected structural damage caused to the rudder system of EI-DPA by violent wind gusts associated with a microburst, while the aircraft was parked.

(c) Contributory Causes

1. The speed of the wind gusts at LPFR considerably exceeded the figure of 65 kts specified in FAR 25.415 Amendment 25-91.

2. The absence of a requirement in the AMM to comprehensively check the flight control systems of an aircraft which has been subjected to an extreme meteorological event.

4. SAFETY RECOMMENDATIONS

No.	It is Recommended that:	Recommendation Ref.
1.	The Federal Aviation Administration should review FAR 25.415, with particular emphasis on those aircraft designs where the multiplying factors set out in the associated NPRM issued in May 2013 may not be applicable.	IRLD2014025

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Appendix A

Summary of the Examinations of the Main and Standby PCUs

Main PCU p/n 419300, s/n 01914

- *Exterior inspection revealed a small impact scar/witness mark on the fastener located on the tail stock mounting tang.*
- *Extruded bonding material was observed at seven individual locations along the seam of one tang of the tailstock. An OEM technician stated that this was frequently observed on PCUs that have been in service.*
- *All fasteners were safety wired with silver seals (factory original seals).*
- *All fasteners were torque striped with no torque slip noted on any fastener.*
- *Cannon plugs were capped.*
- *Hydraulic ports were capped.*
- *Potting compound on joints/seams was undamaged.*
- *The PCU was placed in the test fixture. The OEM technician moved the piston by hand in both directions, and noted normal piston resistance.*
- *Hydraulic lines were connected; the electrical cannon plug was connected and mechanical control input tubes were connected to the input bell crank.*
- *The PCU was subjected to the acceptance test protocol as outlined and documented in TDR 27-21-09 Rev L. No discrepancies were noted.*
- *The bypass valve for system A was removed and inspected. Valve sleeve and spool had matching serial numbers, 7080. No manufacturing defects noted. No unusual wear patterns or marks were noted.*
- *The bypass valve for system B was removed and inspected. Valve sleeve and spool had matching serial numbers, 7081. No manufacturing defects noted. No unusual wear patterns or marks were noted.*

Standby PCU p/n 1001, s/n 2823

- *Cannon plugs were capped.*
- *Hydraulic ports were capped.*
- *Potting compound on joints/seams was undamaged.*
- *No external damage or witness marks were noted on the PCU.*
- *All fasteners were safety wired with silver seals (factory original seals).*
- *All fasteners were torque striped with no torque slip noted on any fastener.*
- *The standby PCU was placed in the test fixture. The OEM technician moved the piston by hand in both directions, and noted normal piston resistance.*
- *Hydraulic lines were connected, electrical cannon plug connected, and mechanical control input tubes connected to the input bell crank.*
- *The PCU was subjected to the acceptance test protocol as outlined and documented in TDR 27-20-70 Rev E. No discrepancies were noted.*
- *The bypass valve was removed and inspected. Valve sleeve and spool had matching serial numbers, 2267. No manufacturing defects were noted. No unusual wear patterns or marks were noted.*

Appendix B

Summary of the Examinations of the PCU Attachment Hardware

Examination of the Standby PCU tailstock revealed the following features:

- *Twisted main bracket – Lower left fractured and features of over stress*
- *Twisted left main overload shear*
- *Twisted right main deformed upper and lower end*
- *Left main upper attach holes UL1, UL2, and UL3 elongated*
- *Left main lower attach holes contain fasteners and fragment of lower trailing edge hinge rib*
- *Right main upper attach hole UR1 slightly elongated, holes UR2 and UR3 appear intact*
- *Right main lower attach hole LR1 elongated, holes LR2 and LR3 appear intact.*

Examination of the standby PCU forward and aft attachment bolts revealed the following features:

- *Both forward and aft bolts are intact, anti-rotation bushing features of over stress*
- *Both forward and aft bolts threads had no evidence of grease.*

Examination of the main PCU tailstock revealed the following features:

- *Left hand lower attach bolts all sheared (4) and remained in bracket – bracket to tailstock appear intact*

Examination of the main PCU forward and aft attach bolts revealed the following features:

- *Both forward and aft bolts intact, rotational rub marks visible on aft bolt bushing, anti-rotation bushing features of over stress*
- *Main PCU forward attach bolt has white residue in thread bottoms*
- *Main PCU aft attach bolt has deposit of grease in thread bottoms.*

Examination of the main trailing edge hinge ribs revealed the following features:

- *Both upper and lower had mating damage consistent with that noted for both main and standby PCU tailstock*
  Overall damage consistent with an overload event.

Appendix C

Photographs of Damaged PCU Support Attachment Hardware

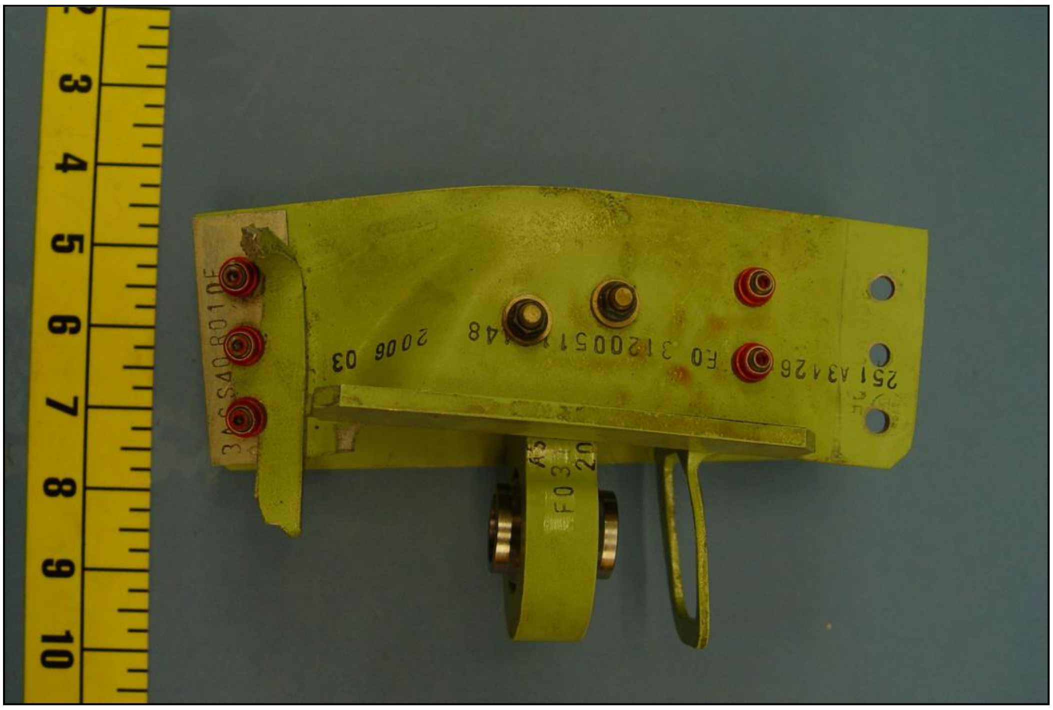

Photo No. C1: Standby PCU Tailstock (Left Side) *(NTSB)*

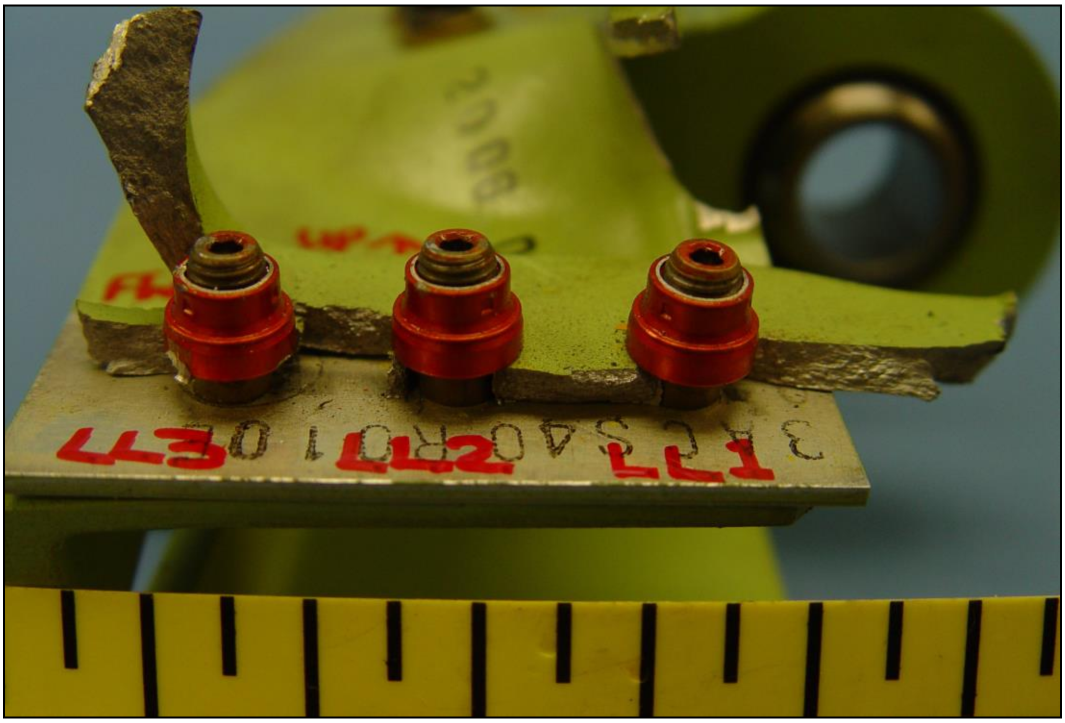

Photo No. C2: Overload stress fracture and shear detail *(NTSB)*

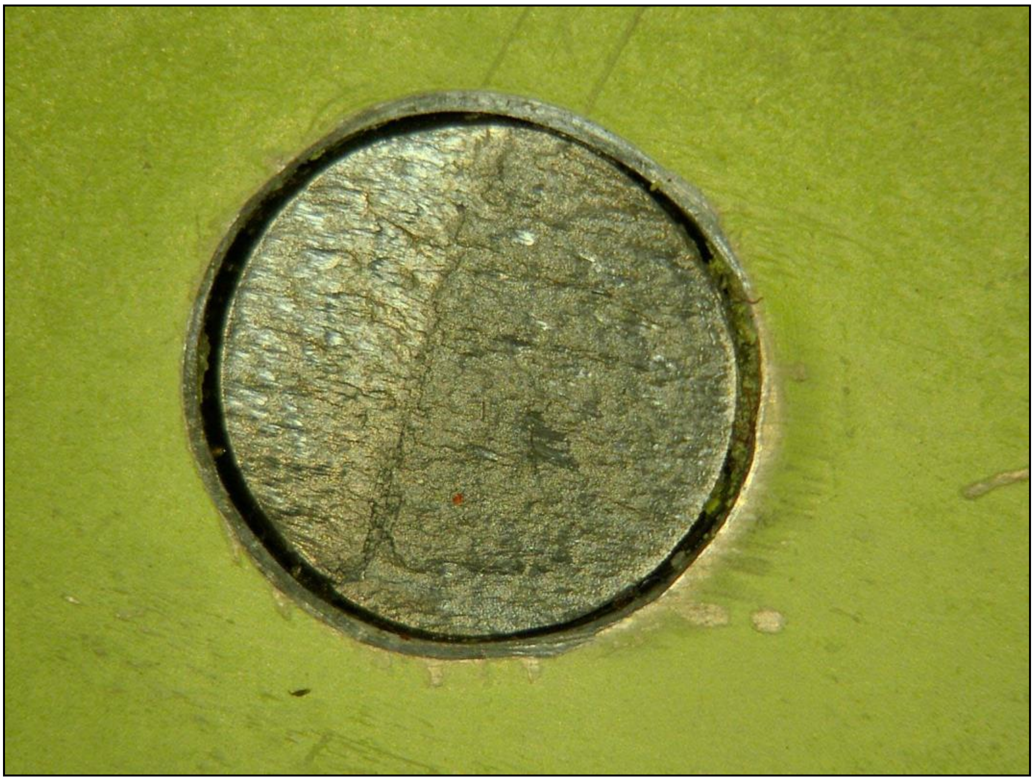

Photo No. C3: Main PCU lower bracket fastener shear *(NTSB)*

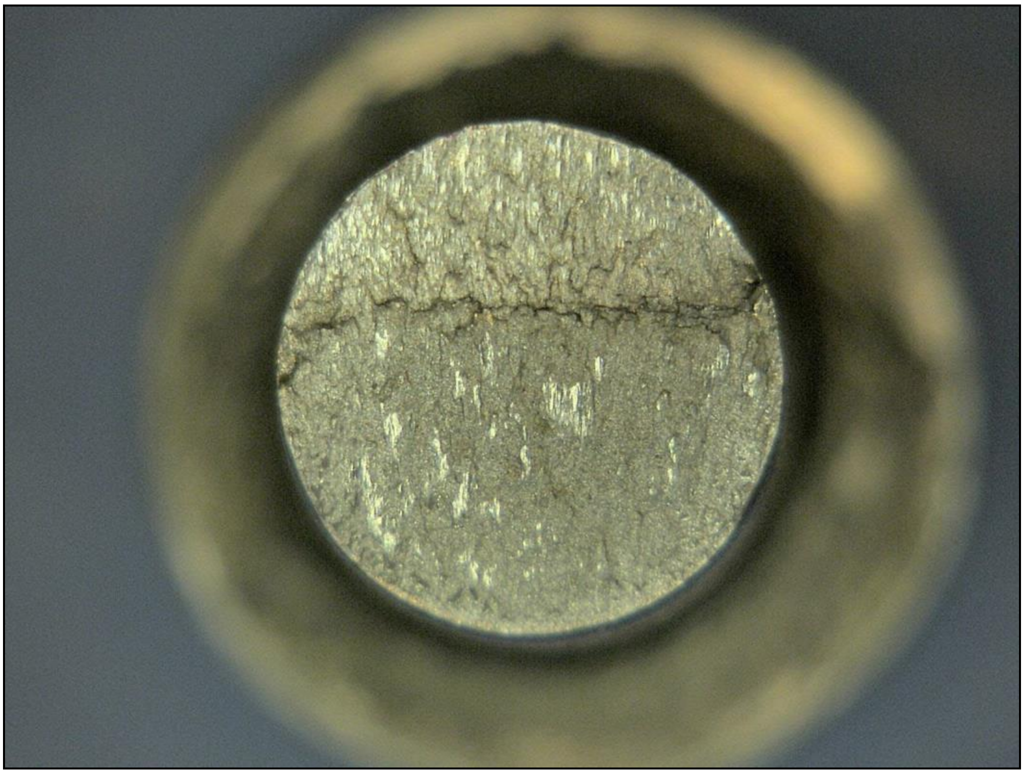

Photo No. C4: Main PCU lower bracket fastener shear *(NTSB)*

– END –

In accordance with Annex 13 to the Convention on International Civil Aviation, Regulation (EU) No 996/2010, and Statutory Instrument No. 460 of 2009, Air Navigation (Notification and Investigation of Accidents, Serious Incidents and Incidents) Regulation, 2009, the sole purpose of this investigation is to prevent aviation accidents and serious incidents. It is not the purpose of any such investigation and the associated investigation report to apportion blame or liability.

A safety recommendation shall in no case create a presumption of blame or liability for an occurrence.

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