Miracle at Beja

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Denis started his flying career as an Antonov 2 First Officer and has 18 years of aviation experience and more than 6500 hours. He has flown the Antonov 12, Fokker 50, Embraer 190, and Embraer 190 E2. Denis is currently a Boeing 767 Captain at Air Astana. In 2019, he joined the airline's Corporate Safety Department and investigates occurrences primarily related to the Embraer 190 fleet. As a Coordinator, Safety, Compliance Flight Operations, Denis is also involved in the flight-management aspects of Air Astana's safety and quality management system and conducts internal and external audits.

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David had an extensive career as a pilot with the Canadian Air Force where he flew a variety of aircraft culminating with the Boeing 707-300. He then joined the Transportation Safety Board of Canada (TSB) and participated in many investigations as IIC, Group Chairman or as Accredited Representative. He has also instructed safety investigation topics at several international locations. David provides assistance and advice to Air Astana and was involved in the initial investigation of the Beja E190 accident and the review of the Portuguese report. He held an Airline Pilot Transport Licence (ATPL) and is a Professional Engineer.

Abstract

On 11 November 2018, Air Astana Flight KC1388, an Embraer E190-100LR, registration P4-KCJ, departed from Alverca do Ribatejo, Portugal (near Lisbon), following scheduled heavy maintenance at a Maintenance Repair Organization (MRO). Shortly after take-off in adverse weather, the pilots had extreme difficulty in controlling the aircraft. At several times, with the aircraft climbing and descending at unusual attitudes, the recovery attempts created structural loads greater than 150 percent of the E190's limit loads. The aircraft had departed with reverse rigging of its ailerons. This paper highlights the human factors and system deficiencies that led to the reverse rigging. It also explores how such a situation went undetected for many days by many maintenance professionals, and ultimately by the pilots as they prepared for departure. The paper also discusses the many lessons learned about accepting an aircraft after heavy maintenance at an MRO. The many positive safety factors demonstrated by the pilots, the air traffic controllers, and the Portuguese Air Force, which resulted in safe landing at Beja after a long and dramatic flight, are also studied.

The Flight

Air Astana KC1388, an Embraer E190-100LR, registration P4-KCJ was expected to be a routine two-segment flight back to Almaty, Kazakhstan, following heavy maintenance at Alverca do Ribatejo Airport, Portugal. This 11 November 2018 flight quickly went from routine to terrifying.

Air Astana had contracted a Maintenance Repair and Overhaul (MRO) facility, Indústria Aeronáutica de Portugal, S.A. (OGMA), to carry out a C2 Heavy Maintenance Check along with the incorporation of several Service Bulletins. The aircraft delivery from OGMA had been delayed several weeks because of apparent computer component problems related to flight controls and some other snags which persisted until the day of departure.

The flight crew for KC1388 consisted of three Air Astana pilots. The captain had more than 6,000 total hours and 4,700 hours in the Embraer E190. The copilot in the right seat for take-off had a total time of 2693 hours, of which 2442 hours were in the E190. A second copilot, who had a total flying time of 3,514 hours, of which 3,084 were in the E190, was in the jump seat. Three staff members from Air Astana's Engineering & Maintenance Department were the only passengers on board.

The weather at the time of departure was rainy with low clouds. The initial portion of the flight was expected to be in instrument meteorological condition (IMC).

On the day of flight, after delays to fix some maintenance snags, the aircraft was finally ready for departure and took-off at 13:31 UTC. Immediately after take-off, while in the adverse rainy weather, the crew felt that the aircraft was not responding correctly to the pilot control inputs. At 13:34:34 the crew declared an emergency "mayday" stating that they had control problems. At 13:47:46 the crew stated that the aircraft was "completely uncontrollable". What followed was an extreme "Rollercoaster" ride that continued for over an hour. At many times, the vertical *G* load was above 4*g*. The peak vertical G was 5.08*g*. At many times the aircraft limit speeds were exceeded, and the vertical speed was as high as 20,000 feet per minute (fpm) down and over 17,000 fpm up. There were many overspeed and Terrain Awareness Warning System (TAWS) audio warnings. Not surprisingly, it was very difficult to move around the aircraft cabin causing one passenger to incur a minor leg injury and some of those on board to be airsick.

What Was Happening?

During troubleshooting by the flight crew, as the aircraft was gyrating violently, the pilots determined that the ailerons were moving in the reverse direction. The wrong movement of the ailerons was confirmed with the cockpit indication. The Air Astana technicians who were passengers assisted the flight crew during the troubleshooting.

Figure 1 Cockpit Indications - Roll Control Movement

The flight crew, after switching several times between the "Direct" and "Normal" Flight Control System (FCS) modes of the flight control systems, decided to keep the system in the "Direct" mode for entire flight. With a trial-and-error learning strategy, the control situation improved significantly, but roll control difficulties remained.

After gaining some aircraft control and when flying to east, while being effectively assisted by air traffic control, the crew found better

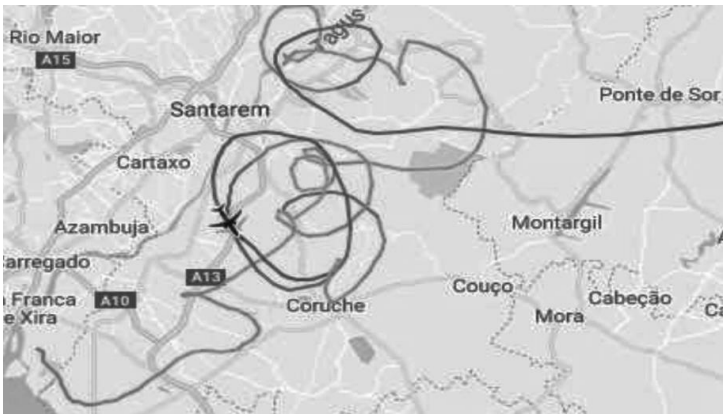

Figure 2 The Flight Path of KC1388

weather conditions that allowed visual cues providing better and more precise action of the aircraft's flight controls.

When the pilots were able to keep altitude and heading, and had sufficient visual references, the aircraft was joined by a pair of F-16 fighters from the Força Aérea Portuguesa (Portuguese Air Force) The F-16s assisted by guiding the flight and coordinating the arrival at the Beja airport, which is a joint military-civilian facility.

The crew of KC1388 first attempted a direct approach and landing on runway 19R at Beja, but the control difficulties resulted in a significantly un-stabilized approach, and they discontinued the landing attempt. Because of the physical exhaustion and unwell condition of the copilot who had been in the right seat throughout the rigorous flight, the captain decided to switch the co-pilots positions after the go-around. The jump-seat co-pilot assumed the right seat position and completed the landing after one more go-around. The intended runway was 19R, however the aircraft drifted to the left. The pilots realized that they could salvage a landing on 19L and were successful in landing on the narrower runway.

After the aircraft was taxied to the ramp, all onboard the aircraft were undoubtedly grateful that they had survived their 2-hour ordeal. On shutdown a FLT CTRL NO DISPATCH message was displayed on the E190's EICAS.

What Happened

The ailerons were mis-rigged during the heavy maintenance. This reverse rigging was not detected during the rigging process, the maintenance release, nor by the flight crew before take-off.

In accordance with the International Civil Aviation (ICAO) Annex 13, this accident was investigated by the Gabinete de Prevenção e Investigação de Acidentes com Aeronaves e de Acidentes Ferroviários (GPIAAF) of Portugal. The Portuguese investigation and report endeavoured to determine the "Whys" that resulted in the accident and some of these will be highlighted.

Why was the occurrence an accident?

There was structural damage because of the violent flight maneuvers. Some areas of the aircraft experienced more than 150 per cent above the limit loads. After the aircraft landed at Beja, wrinkled skin was noted on the fuselage and wings. Also, the wing dihedral on rib 26 revealed to be out of tolerance, showing a permanent deformation. All wing fixed leading edges were found wrinkled. The wing damage geometry was found sharper on the forward and aft regions, and

smoother on inboard and outboard regions, indicating that the damage was caused by wing bending around the wing chord direction. The structural damage deemed this occurrence to be an accident.

Why were the ailerons mis-rigged?

In addition to a C2-Check, OGMA also carried out the work related to the accomplishment of several Service Bulletins (SB). One of the SBs, SB190-57-0038R2, changed the type of routing of the ailerons' control cables, with the replacement of pulleys and respective structural supports by a non-contact support, aiming to reduce the control cable friction on that area. The structural work, with the removal and crimping of the supports in the rear wing spar in the fuel tank area, also required the complete disconnection of the control cables.

Then, SB190-27-0037R1 was accomplished, which consisted of replacing the installed stainless-steel control cables by carbon steel cables. The investigation revealed maintenance errors and inconsistencies during this work. The C-Check work interrupted the installation procedures for the aileron control cables on several occasions. Some procedures had to be put on hold and some checks were not completed including the ailerons correct movement physical check as per the Aircraft Maintenance Manual (AMM).

In addition, the investigation noted that the aircraft manufacturer did not provide proper and clear maintenance instructions for the aileron control system installation and operational checks. Some of the diagrams were unclear and apparently the OGMA Technicians had difficulty interpreting the instructions. As a result, the newly installed aileron cables crossed each other near rib 19-23 (see figure 3).

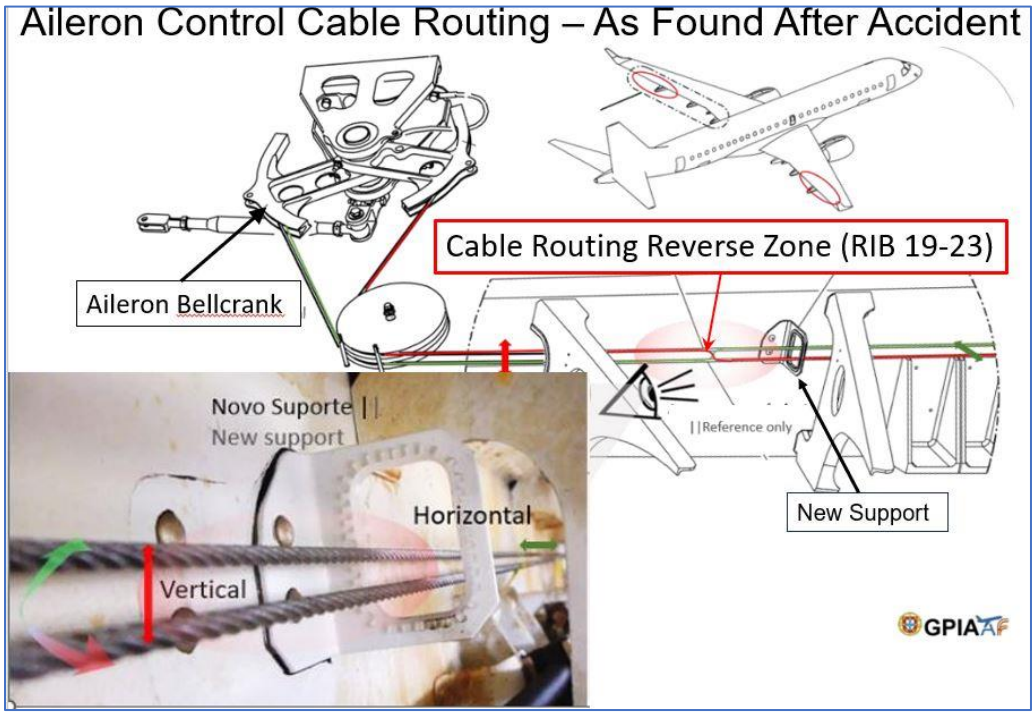

Figure 3 Aileron Control Cable Routing

Why was the reversed rigging not detected during maintenance?

EASA Annex 11, Part 145.A.48 regarding independent Inspections states:

> When inspecting control systems that have undergone maintenance, the independent qualified person should consider the following points independently:..(4) the operation of the control system, as a whole, should be observed to ensure that the controls are operating in the correct sense; (5) If different control systems are interconnected so that they affect each other, all the interactions should be checked through the full range of the applicable controls…"

The investigation revealed that independent inspections procedures were not performed. The GPIAAF Report stated "…the tasks classified with the independent inspection requirement were not accomplished according to the procedures established in the regulation.

On 26 Oct, following the operational tests after aircraft power-up, a FLT CTRL NO DISPATCH message appeared in the EICAS indicating that the aircraft could not be dispatched for flight due to problems related with the flight control system. At least 12 changes or swaps of the four Flight Control Modules (FCM) were made in attempts to clear the "FLT CTRL NO DISPATCH" message. The aircraft manufacturer was consulted during the troubleshooting related to the "FLT CTRL NO DISPATCH" message. Apparently, clearance of a "FLT CTRL NO DISPATCH" message was not possible until a control module with a recorded fault on its memory was replaced.

The last replacement (FCM2) was made on 11 Nov, the day of the accident. Then, after six power-down and power-up sequences, the "FLT CTRL NO DISPATCH" message did not re-appear following the flight controls system return to service (RTS) procedure. After this last-performed procedure, on the morning of the flight, the FCM maintenance status page showed only FCM2 with a green status after the test (RTS).

In summary, interrupted maintenance procedures, a lack of understanding of the Maintenance Manual instructions, no independent checks by the MRO maintenance teams meant that the aileron mis-rigging went undetected. Another important element in chain of events leading to accident is that with continuing flight control problems, no one went back to basics and checked for correct control surface movement.

Why Did the Pilots Not Detect the Aileron Mis-rigging?

KC1388 was not a "routine" flight but was a flight where many safety-critical systems were affected by the maintenance work at OGMA. Yet, normal procedures and checklists were used. There were no special checklists used for KC1388. The pre-flight checks did not focus extra attention on aircraft systems that had received maintenance.

The control check was carried out and the crew noted that the controls moved but did not detect the wrong sense for the aileron movement. The investigation noted that the Air Astana Standard Operating Procedures (SOP) 2-25, derived from the aircraft manufacture's SOP, lacked detail regarding control surface movement direction.

From a human factors perspective, a “slip” is an unintentional error which includes actions performed on “automatic mode” behaviour action. This error type includes, skipping or reordering a step in a procedure, performing the right action on the wrong object, or performing the wrong action on the right object. It is a skill-based error type that tends to occur during highly routine activities, when attention is diverted from a task, either by thoughts or external factors. One could conclude that the pilots missed detecting the incorrect aileron rigging because of “slip” errors.

There are many examples where incorrect control rigging was not detected during pre-flight checks by very experienced and professional pilots. No one is immune. For example, in a 2019 Global 5000 accident involving some Flugbereitschaft BMVg VIP pilots, they did not detect reverse spoiler movement following maintenance.

Why the Pilots Were Able to Regain Enough Control to Land at Beja?

The aircraft roll controlled reacted in a way opposite to that expected by the pilots from their knowledge, training and experience and they had to adapt their roll-control inputs to the reality of the reverse aileron rigging.

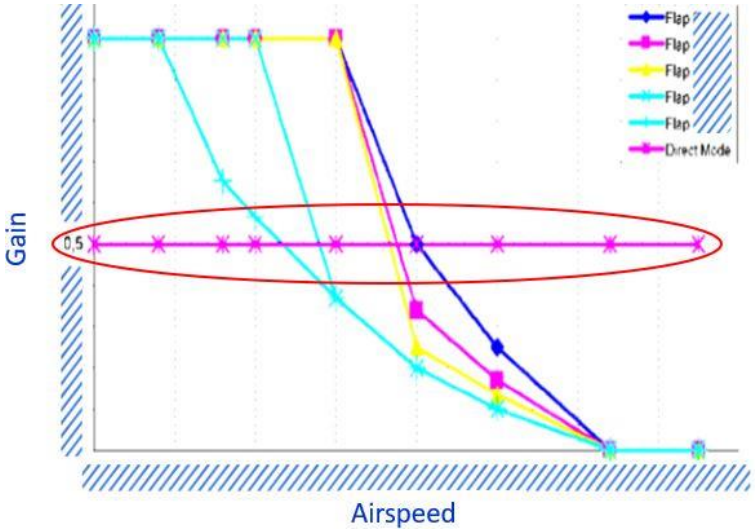

Figure 4 Performance of the FCS Roll Augmentation Modes

The pilot’s decision to use “Direct” FCS Mode made the reverse roll performance more predictable and removed the variable of control gain, from their flight control problems (see Figure 4)

During the high-*G* forces and very unusual attitudes, the pilots showed resilience and managed to regain enough control to consider landing at an airport.

As one can imagine, the flight forces were physically very tiring. The decision by the captain to replace the copilot, who had endured the nearly 2-hour physically difficult flight, with the jump-seat copilot and have him complete the landing was a very effective use of pilot resources. The pilots also used the expertise of the airline’s technical team who were traveling as passengers while troubleshooting the control problems.

Maintenance Lessons Learned

Safety Action by Embraer – From GPIAAF Report

“Embraer made important changes to the approved instructions and procedures, such as changing aileron control cables replacement task adding clearer instructions and using figure colouring on SB 190-57-0038 aileron control cables – fairleads and grommet replacement related instruction, the SB for cable material replacement and also on the operational task to check the ailerons position.”

OGMA realized that they needed a process of continuous restructuring of productive areas aiming solutions for an error capture and increased barriers (named quality gates) and needed a strategy to allocate a dedicated and independent inspector team (out of production team).

There was another important maintenance lesson. If extraordinary measures are required to clear a “FLT CTRL NO DISPATCH” EICAS message following flight control maintenance, go back to basics and check the correct control rigging (direction and configuration).

Operations Lesson Learned

Maintenance Test Flights are not “Routine”! Extra detailed checking of systems that have been affected during maintenance is needed. Thus, an aircraft acceptance checklist was introduced for use after significant maintenance intervention. The checklist informs the crews as to which systems were disturbed during the maintenance. Air Astana also re-established Maintenance Check Pilot qualifications.

The adverse weather during the accident greatly increased the pilots’ workload and thus the airline established requirements for visual meteorological weather conditions (VMC) weather minimums for flights following heavy maintenance.

The Air Astana checklist has been revised for both pilots to check the correctness of ailerons, rudder, elevator and multifunction spoiler surfaces deflection in respect of the flight control column movement utilizing the flight controls synoptic page.

A positive lesson learned was the importance of the effective assistance provided by Air Traffic Control and the Portuguese Air Force the

On another positive note about lessons learned (or re-learned), effective Crew Resource Management (CRM) and flight crew resilience are essential when dealing with unusual or emergency conditions. A safety and training culture of continuous improvement is critical in the development of these skills.

It was a Miracle!

A miracle is defined as a highly improbable or extraordinary event, development, or accomplishment that brings very welcome consequences. This certainly was the case on 11 November 2018 for the crew and passengers of KC1388.