

Embraer EMB-145EP, G-RJXC

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INCIDENT

Aircraft Type and Registration: Embraer EMB-145EP, G-RJXC

No & Type of Engines: 2 Allison AE3007A turbofan engines

Year of Manufacture: 1999

Date & Time (UTC): 15 February 2002 at 1430 hrs

Location: East Midlands Airport

Type of Flight: Public Transport (Passenger)

Persons on Board: Crew - 4 Passengers - 44

Injuries: Crew - None Passengers - None

Nature of Damage: None

Commander's Licence: Airline Transport Pilots Licence

Commander's Age: 43 years

Commander's Flying Experience: 3,820 hours (of which 127 were on type)

Last 90 days - 127 hours

Last 28 days - 54 hours

Information Source: AAIB Field Investigation

History of the flight

The following has been compiled from the evidence of the crew and data extracted from the Digital Flight Data Recorder (DFDR). The data extracted from the DFDR is presented in Figure 1 (*jpg 100kb*).

The aircraft was scheduled to fly from Leeds Bradford International Airport, Yorkshire, to Charles De Gaulle Airport, Paris, departing at 1335 hrs. The departure and initial climb were uneventful but, as the aircraft was passing flight level (FL) 250, the crew were alerted by a MAIN DOOR OPN (open) warning message on the Engine Indication and Crew Alerting System (EICAS). Shortly thereafter the crew noticed an EICAS HYD 2 LO QTY (hydraulic low quantity) advisory message.

The commander, who was the handling pilot, levelled the aircraft at FL270 and prepared to refer to the Quick Reference Handbook (QRH) Emergency and Abnormal Procedures, but before he could

do so the MAIN DOOR OPN warning extinguished. Meanwhile, the first officer had selected the Hydraulics System page on his Multi Function Display (MFD), which showed the No 2 hydraulic system fluid quantity in the amber range, indicating that hydraulic fluid quantity was less than one litre.

The crew carried out the HYDRAULIC SYSTEM LOW QUANTITY checklist from the QRH and, after some discussion, decided to divert to land at East Midlands Airport. Shortly after commencing diversion procedures with ATC, the commander noticed that the No 2 hydraulic fluid quantity was continuing to decrease and he therefore asked the first officer to carry out the HYDRAULIC SYSTEM 2 FAILURE checklist.

The aircraft was given radar vectors for an approach to Runway 27 at East Midlands Airport. As the aircraft passed abeam the airfield, with flap 9° extended, the crew became concerned that the No 1 hydraulic system fluid was also decreasing. Not wishing to be faced with a landing with the flight controls in manual mode, the crew requested an expedited approach, and the commander selected the speedbrakes to OPEN. Both crew members recalled that the speedbrakes opened normally and the DFDR showed normal speedbrake extension at a speed of 207 kt. When the commander selected the speedbrakes to CLOSED, 33 seconds later, both crew members recalled seeing the EICAS speedbrake indicator showing CLD (closed) after the spoilers retracted. One second before the speedbrakes closed, the DFDR recorded a Master Caution event for six seconds and low pressure on No 2 hydraulic system, which remained until after landing.

Thirty four seconds later, and uncommanded, the right outboard spoiler opened and two seconds later the left outboard spoiler opened. Ten seconds after the right spoiler opened, the Master Caution aural alert tone sounded. The crew could not recall with certainty which EICAS caution appeared, but later considered that it was probably a SPOILER FAIL message. The speedbrakes remained open for 35 seconds, then both spoilers closed. About 28 seconds later, as the crew selected flap 22°, the left spoiler opened and the Master Caution and OPN indication reappeared and remained until touchdown.

At about 3 miles from touchdown, the crew selected landing flap 45° and, almost immediately the commander noticed that the autopilot, which had been engaged throughout, was applying right aileron to maintain wings level. Twelve seconds after selecting flap 45°, and with 17° of right control wheel applied, the commander disengaged the autopilot and subsequently required an increasing amount of right aileron to maintain the aircraft wings level, until almost full right aileron was applied. The commander asked the first officer to assist by operating the aileron trim and, having assessed that the aircraft was controllable, decided to continue the approach to land. The DFDR recorded that 20% right control trim and 20% right control wheel were maintained during the approach until, at about four seconds from landing, the roll trim was increased to 85% right.

The landing was uneventful and the DFDR recorded that, as the air/ground status changed, both inboard spoilers opened as a result of ground spoiler command. Thirty seconds after touchdown, and one second before the ground spoilers were commanded to close, the No 2 hydraulic low pressure indication disappeared and the right outboard spoiler opened. One second later the inboard spoilers closed and the No 2 hydraulic low pressure indication reappeared.

In the latter stages of the landing roll the EICAS BRAKE OVERHEAT caution activated and the crew therefore brought the aircraft to a halt clear of the runway and requested fire service assistance. The fire service found no signs of fire, but the aircraft was shutdown and towed to a parking stand where the passengers disembarked normally.

At the time of the incident, the weather was fine with only a few scattered clouds and no icing conditions were encountered. The surface wind at East Midlands Airport was recorded as being variable at 2 kt, with winds between the surface and 2,000 feet being from north to north-westerly at 10 to 15 kt.

EICAS Architecture

Engine indications, and some system parameters, are presented to the crew on the EICAS display, located on the centre panel of five flight deck displays. Crew awareness messages are presented in the upper right corner of the EICAS display and are prioritised into one of three message levels.

Warning messages are coloured red and require immediate crew action. They are presented at the top of the list in the order that they occur. They are accompanied by an aural tone and a flashing Master Warning light on the glareshield panel.

Caution messages are coloured amber and require immediate crew awareness. They are presented below any warning messages. They are accompanied by an aural tone and a flashing Master Caution light on the glareshield panel.

Advisory messages are coloured cyan and are displayed for minor failures. They are presented after Caution messages in the list.

When a message is first generated it is displayed, flashing, at the top of the appropriate group. On receipt of a message the crew are required to refer to the QRH to carry out the appropriate emergency or abnormal drill.

Flight Controls Description

The EMB-145 aircraft utilises two hydraulic systems, each driven by an Engine Driven Pump (EDP) to power primary and secondary flying controls (not elevators, pitch trim or flaps), landing gear and spoilers/speedbrakes etc. As shown in Figure 2 (*jpg 80kb*), the primary flying controls are powered by both systems but the outboard spoilers (speedbrakes) are powered only by No 2 system. No 1 system powers the inboard spoilers, which can be deployed only on the ground. In flight, selection of speedbrakes by the pilot raises the outboard panels fully (there is no proportional deployment). On the ground, both inboard and outboard panels deploy automatically provided that the ground speed is sensed to be above 25 kt.

Both inboard and outboard spoiler panels employ similar actuating jacks, with a lock mechanism for the closed position. When commanded to open, hydraulic pressure is ported to the actuators, which first releases the locks and then moves the jacks to deploy the panels. When commanded to close, hydraulic pressure is ported to the other side of the jacks and the locks mechanically engage as the panels reach their fully closed position. The EICAS (and DFDR) indications of OPN and CLD are derived from proximity sensors, which have some tolerance to prevent intermittent spurious indications during turbulence etc. In practice, this means that the CLD indication can be displayed when the panel is not quite closed and the lock not engaged. There is no interlinking to prevent asymmetric deployment of the spoiler/speedbrakes.

As part of the aircraft certification process, the manufacturer was required to demonstrate the aircraft's capability for continued safe flight and landing following the jamming of one speedbrake panel in the fully deployed, floating position. During flight test of this configuration, the aileron

displacement required to keep the wings level during manoeuvre with flaps up and at 9° was found to be up to one third of full range. With flaps at 22°, up to half aileron was required. Full aileron was required with flaps at 45°. Because of the reduced lateral control margin with the flaps at 45°, it was decided to limit landings with a floating spoiler to the flap 22° configuration.

Examination of the Aircraft

The aircraft was examined in a hangar at East Midlands Airport. Apart from essential shutdown items, it had been left in the configuration in which it arrived. Flaps were in the 45° position, the spoilers were closed and locked and aileron trim was set almost fully right-wing-low. Hydraulic oil was leaking from the right engine cowling and the No 2 system reservoir was almost empty. No 1 system contents were normal. When power was applied to the aircraft, the EICAS hydraulic system contents were indicating at the bottom of the amber range (No 2 system) and about two-thirds up the green range (No 1 system).

Tests were then conducted on a serviceable aircraft of the same type, to establish whether it was possible to obtain a CLD indication on the EICAS display without the speedbrake panel being in a locked condition. This was achieved by powering the speedbrakes to deploy, shutting-off hydraulic power, dissipating pressure and then selecting CLOSED. The panels could then be inched down by hand, stopping at the point where the OPN indication changed to CLD. This was found to occur when the trailing edge was still raised about 20 mm, and the actuator lock was not engaged. Since, before the CLD condition was reached, there was a disagreement between the lever position and the surface position, a SPOILER FAIL caution was expected. This did occur, but it was noted that there was a 10 second delay before the caution appeared. This timing is apparently correct by design.

The No 2 system hydraulic leak was traced to a loose connection of the EDP case tube drain union located in the engine/fuselage stub wing. There was no evidence to suggest that any recent maintenance tasks had been carried out in this area. The apparently unrelated main door open warning was not reproduced on the ground and, since no defects were found, it would appear to have been spurious.

Flight Manuals and Checklists

Emergency and Abnormal procedures are published in the Aircraft Flight Manual (AFM), the QRH and the Airplane Operations Manual (AOM). The manufacturer publishes the AFM for approval by the appropriate certification authority. The AFM is a legal document, which provides the base line for aircraft operations. The AOM and the QRH are also produced by the manufacturer, but tend to contain more detailed and practical information for flight crews. Airlines are required to produce their own Operations Manual (OM), which must comply with the AFM, under the terms of their Air Operators Certificate. In practice, airlines tend to use the manufacturers AOM, and adapt it, to a greater or lesser extent, to suit their style and type of operation. The airlines OM must not contain information contrary to the AFM, although more conservative data and procedures than those contained in the AFM may be used. In this particular case, the operator had adopted the manufacturers AOM almost without amendment. A statement at the front of the manufacturers QRH makes it clear that where there are discrepancies between the QRH and the AFM the latter must prevail.

Checklists and procedures used by the crew in this incident were identical to those issued by the manufacturer. However, it became apparent during the investigation that there were significant discrepancies between QRH and AFM procedures.

The AOM contains information on aircraft systems. Although it became clear, from examination of the notes to the INADVERTENT SPOILER OPENING IN FLIGHT checklist, that the possibility of an unlocked and floating spoiler was a known problem, no other reference to the possibility could be found elsewhere in the Manual.

Furthermore, neither the commander nor the first officer involved in this incident could recall being briefed on the possibility during their recent type conversion training. The type rating training course undertaken by the crew did not include specific reference to the potential floating spoiler asymmetry condition. Although referred to in the QRH drills for hydraulic system malfunctions, which formed part of the flight simulator phase of the training, the practical aspects were not able to be covered in detail as the simulator was not programmed to replicate this type of fault condition.

The QRH HYDRAULIC SYSTEM LOW QUANTITY checklist advises the crew to monitor the affected hydraulic system and to carry out the relevant HYDRAULIC SYSTEM 1 OR 2 FAILURE checklist as required. However, the failure drill does not inhibit a system, because it does not isolate the EDP. The only time this is done is in the event of an engine fire, when a valve is closed at the inlet to the EDP. Since this would cause pump cavitation and consequent damage over an extended period of running, it is considered appropriate only in the case of a serious emergency. Thus, hydraulic pressure will remain normal, even after the hydraulic failure checklist has been completed, provided that hydraulic fluid is available and that the EDP is serviceable. Failure of either hydraulic system will result in the loss of some wheel brakes, with the result that the crew are required to take into account an increase in the landing distance required.

Detailed examination of the QRH HYDRAULIC SYSTEM 1 OR 2 FAILURE checklist revealed a number of inoperative items which remained operative, but had lost some redundancy. In addition, the HYDRAULIC SYSTEM 1 OR 2 FAILURE checklist takes no account of the possibility of the hydraulic failure occurring with the speedbrakes deployed and neither does it mention the possibility of spoilers failing to lock closed if such an event occurs.

The QRH Index of EICAS messages directs the crew to the appropriate checklist to be followed. In the case of the SPOILER FAIL message the crew are directed to a checklist entitled INADVERTENT SPOILER OPENING IN FLIGHT. This checklist begins with a list of associated EICAS messages and presents a CONDITION, which describes symptoms that may accompany the failure. In this case the CONDITION that may accompany the SPOILER FAIL message is Sudden airspeed or altitude loss. The checklist then includes a set of boxed items, which are required to be accomplished by the crew from memory:

Control the airplane using thrust, elevator and stabiliser.

Speedbrake Close

The remainder of the checklist, which is not accomplished by memory recall, requires a flap 22° configuration landing. It also provides a CAUTION that outlines the increase required to landing distance dependent on whether the spoilers are jammed closed, floating or jammed open.

Analysis

The MAIN DOOR OPN warning that took place at the beginning of this incident was an isolated, unrelated event, which will not be considered further.

The No 2 system hydraulic leak was traced to a loose connection of the EDP case tube drain union located in the engine/fuselage stub wing. As there was no recent history of maintenance being carried out in this area, it was concluded that the union had loosened as a result of in-service vibrations. There was no evidence to suggest that this was a common problem on this type of aircraft, so no further action was considered to be appropriate.

Faced with a HYD 2 LO QTY message, the commander decided to divert to East Midlands Airport. The crew carried out the HYDRAULIC SYSTEM LOW QUANTITY checklist and, on noticing that the fluid quantity was still decreasing, the commander decided to carry out the HYDRAULIC SYSTEM 2 FAILURE checklist. The HYDRAULIC SYSTEM LOW QUANTITY checklist states that the HYDRAULIC SYSTEM 1 OR 2 FAILURE checklist should be carried out as required. The commanders interpretation of this instruction was that he could carry out the checklist when operationally convenient. Given the need to check the available landing distance, as a result of degraded landing performance, the decision to carry out the HYDRAULIC SYSTEM 2 FAILURE checklist, before reaching the critical landing phase, was sensible. However, it placed the crew in the unusual situation of having normal hydraulic pressure on both systems, but with the HYDRAULIC SYSTEM 2 FAILURE checklist complete.

Later, during the diversion to East Midlands Airport, when the crew became concerned that the No 1 system fluid quantity was also decreasing, the commander requested reduced distance to touchdown and, with No 2 hydraulic system pressure indicating normal, decided to use the speedbrakes to expedite the descent. Whilst in retrospect the advisability of extending the speedbrakes in these circumstances might be questioned, there was nothing in the HYDRAULIC SYSTEM LOW QUANTITY or HYDRAULIC SYSTEM FAILURE checklists to advise against the action and the crews overriding concern at the time was to get on the ground expeditiously.

Examination of the aircraft after the incident failed to reveal a problem with the No 1 hydraulic system, and it is therefore assumed that the indicated reduction in No 1 system fluid quantity was transient and the result of normal system demands.

DFDR data indicated that the No 2 system hydraulic pressure finally failed, almost at the same time that the speedbrakes were retracted. It seems likely, in light of subsequent events, that the pressure failed before the speedbrakes had reached the fully closed and locked position. Thus, although the EICAS indicated the spoilers were CLD, both outboard panels remained unlocked and, 33 seconds later, probably due to changing aerodynamic loads resulting from a pitch change, the right spoiler, followed two seconds later by the left spoiler, floated open.

Ten seconds later, the DFDR showed activation of the Master Caution event. Although the nature of the caution is not recorded, crew evidence and systems analysis indicates that it is likely to have been a SPOILER FAIL message. The DFDR data showed that the message would have been present on the EICAS for 20 seconds, before the spoilers closed under aerodynamic loads. Thereafter, the right spoiler remained closed until after touchdown. Although other explanations are possible, it appears likely that when both spoilers floated closed for the second time, the right locked down but the left remained unlocked. Had this not happened, then both spoilers would have

continued to float to roughly the same degree, and the subsequent lateral control asymmetry would not have occurred.

Thirty seconds later, the left spoiler opened under aerodynamic loads, coincident with the selection of flap 22° and, 10 seconds later, the Master Caution was activated. Again, this is likely to have been a SPOILER FAIL message. At this point, the aircraft was less than two minutes from touchdown and it is therefore not surprising that, after a previous similar intermittent warning, and an overriding concern that there was a possibility of a total hydraulic failure, the crew chose not to consult the QRH. However, if they had found time to do so, the INADVERTENT SPOILER OPENING IN FLIGHT checklist would have advised them to limit flap to 22° for landing.

Given the large amounts of right aileron required during this incident, it would appear that the left spoiler floated open by a significant amount once flap 45° had been selected. The opening of the right spoiler during the landing roll appears to be due to a transient recovery in No 2 system hydraulic pressure perhaps as a result of deceleration forces making the remaining fluid available to the pump.

This incident has raised a number of concerns regarding the AFM and QRH checklist.

Both crew members had completed their type training relatively recently, yet neither had been aware or briefed of the possibility of a floating spoiler. The INADVERTENT SPOILER OPENING IN FLIGHT checklist is included in the AFM, the QRH and the AOM, but reference to the possibility of a floating spoiler is limited to a brief note at the bottom of the checklist. The type rating training course undertaken by the crew did not include specific reference to the potential floating spoiler asymmetry condition. Although referred to in the QRH drills for hydraulic system malfunctions, which formed part of the flight simulator phase of the training, the practical aspects were not able to be covered in detail as the simulator was not programmed to replicate this type of fault condition. In view of the potential for serious control problems, it is therefore recommended that the manufacturer include an explanation and the implications of a floating spoiler in an appropriate place in the aircraft manuals available to crews.

Since this incident the manufacturer has produced a number of draft amendments to the QRH and AFM:

To reduce the probability of a floating spoiler occurring as the result of a hydraulic system 2 failure, both the HYDRAULIC SYSTEM LOW QUANTITY and the HYDRAULIC SYSTEM 1 OR 2 FAILURE checklists will be amended to include a warning that speedbrake should not be used.

The HYDRAULIC SYSTEM 1 OR 2 FAILURE checklist in the AOM and QRH includes references to systems that lose redundancy as a result of hydraulic failure but are listed as inoperative, and as a result there is the potential for confusion. The manufacturer has produced draft changes to the HYDRAULIC SYSTEM 1 OR 2 FAILURE checklist that clarify system status.

The INADVERTENT SPOILER OPENING IN FLIGHT checklist includes: EICAS Caution: SPOILER FAIL and CONDITION: Sudden airspeed or altitude loss and the AFM version of the checklist differs significantly from the QRH version. As a result of system architecture the SPOILER FAIL message may or may not be present with an unscheduled spoiler opening and the stated CONDITION did not occur in this incident. There is therefore the potential for crew

confusion, and the manufacturer has produced a draft checklist that amplifies the information provided to avoid the possible confusion. The inconsistency between the AFM, AOM and QRH was not limited to this checklist and it is therefore recommended that the manufacturer review all AFM, AOM and QRH checklists to ensure consistency.

Safety Recommendations

The following Safety Recommendations are made:

Recommendation 2002-45

Embraer should highlight the potential for floating and asymmetric spoiler condition in an appropriate place in the aircraft manuals available to crews.

Recommendation 2002-46

Embraer should complete the proposed amendment process for the EMB-145 series Quick Reference Handbook :

- To include a warning in the HYDRAULIC LOW QUANTITY checklist and the HYDRAULIC SYSTEM 1 OR 2 FAILURE checklist that speedbrake should not be used.
- To clarify system status in the HYDRAULIC SYSTEM 1 OR 2 FAILURE checklist.
- To clarify the EICAS message and CONDITION in the INADVERTENT SPOILER OPENING IN FLIGHT checklist.

Recommendation 2002-47

Embraer should review the content of the EMB-145 series Airplane Operations Manual, Aircraft Flight Manual and Quick Reference Handbook in order to ensure consistency in all procedures.