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Bureau d'Enquêtes et d'Analyses
pour la sécurité de l'aviation civile

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REPORT
SERIOUS INCIDENT

Failure of an autopilot control cable, stiffening of elevator control during flare

Aircraft	Bombardier CRJ700 registered F-GRZN
Date and time	July 12, 2010 at around 18:30 UTC[1]
Operator	Brit Air
Place	Bilbao Airport (Spain)
Type of flight	Scheduled public transport of passengers
Persons on board	2 flight crew, 2 cabin crew 63 passengers, 2 babies
Consequences and damage	None

[1]Except where otherwise stated, the times shown in this report are expressed in Universal Time Coordinated (UTC).

HISTORY OF FLIGHT

The crew was performing the first leg of its round trip, departing from Bilbao bound for Paris Charles de Gaulle. During climb, the crew noticed that the aircraft autopilot was unable to hold the engaged vertical mode. An "AP PITCH TRIM" caution message was displayed. The crew applied the corresponding check-list which, after another unsuccessful attempt at AP engagement, led the crew to resume manual control. They then decided to make several attempts at AP vertical mode engagement, which confirmed that it did not hold any of these modes. The flight continued to its destination without any further events.

At the stopover, the maintenance service took a variety of steps relating to the problem encountered. No malfunctions were found. Specifically, the elevator servo operational test was performed three times and free clearance of the controls was checked. The Certificate of Release to Service (CRS) was signed and the crew decided to fly the next leg, bound for Bilbao.

During this leg, the same problem occurred: the AP could not hold the vertical modes and the "AP PITCH TRIM" caution message triggered. The flight continued under manual control.

During the flare at Bilbao, the crew had to exert greater effort than usual at the flare. However, the touchdown was normal. While taxiing, they noticed that the elevator control blocked at half way pitch-up. The following flight was cancelled.

The maintenance operations performed following this incident revealed that the AP pitch-up elevator control cable was broken and that the free part of the cable, by forming a loop, had blocked the AP servo.

End of the broken cable, held in its housing in the quadrant, seen through a mirror

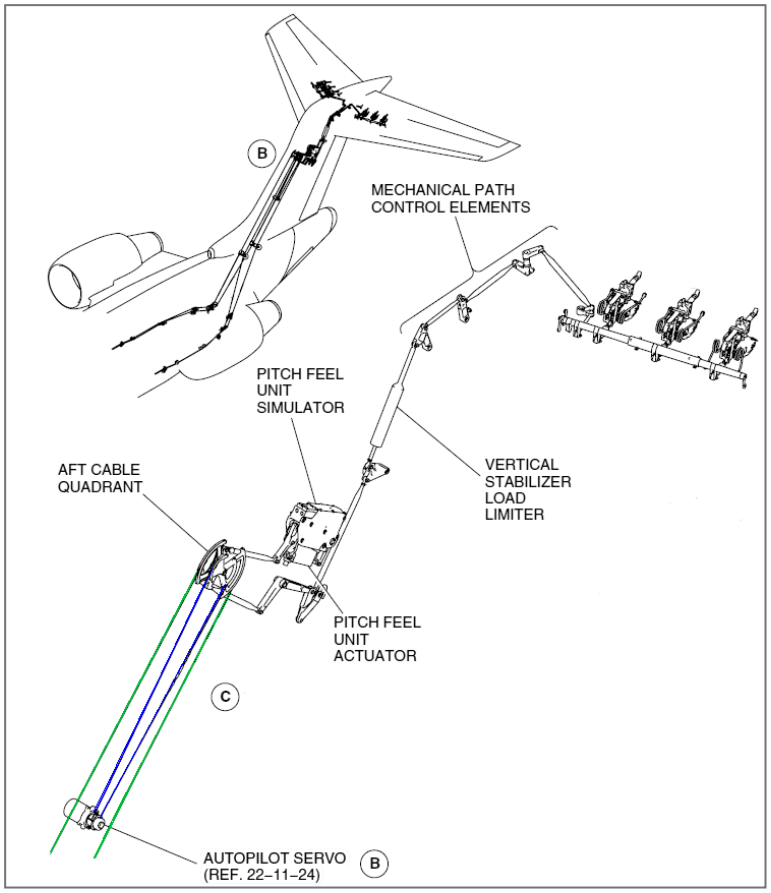
Loop formed by free part of cable that blocked the autopilot servo

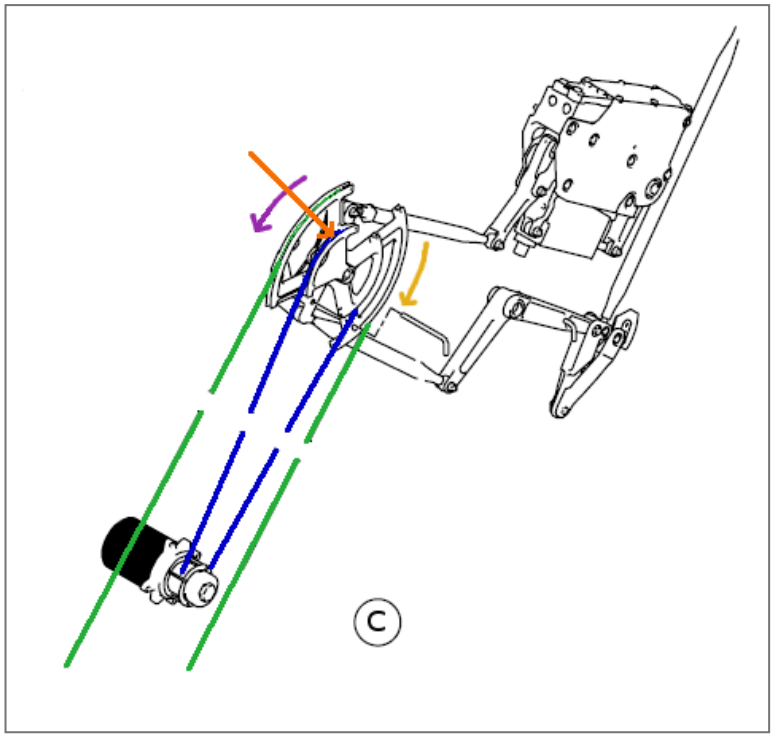
ADDITIONAL INFORMATION

Technical description of elevator path control elements

The elevator consists of two surfaces, one on either side of the tail plane. Each surface is connected to the control column located on the same side. The two control columns are connected by a separable mechanical system. Thus, if the elevator control path blocks on one side, the crew can separate the two control columns and control the aircraft using the remaining half of the system.

The AP pitch control system is installed in parallel on the control path, located on the captain's side. The AP pitch control servo is connected by two cables (one for pitch-up actions, the other for pitch-down actions) to a quadrant which is itself part of the manual control path quadrant of the elevator. Thus, an autopilot input on the elevator translates into a control column movement in the cockpit.





Key for both images

Diagrams of system (manual control path in green, automatic control path in blue; orange arrow indicates failure; yellow arrow indicates direction of rotation given to quadrant for an elevator pitch-down movement; purple arrow corresponds to a pitch-up movement)

Failure

Examination of the data from the FDR showed that the cable broke during the ILS final on arrival at Bilbao, during the last leg performed before the crew took over the aircraft. The approach was performed in AP until, following a vertical flight path excursion by the plane at approximately 1,200 ft (1,150 ft radio altimeter), the crew took over control and finished the approach manually. This crew did not attach any great importance to this behaviour and did not make a note of it in the log book or mention it to the following crew. The first "AP PITCH TRIM" caution message occurred during the following flight.

The failure occurred on the pitch-up cable, in line with the crimped cable end. The crimped cable end in its notch remained in the aft quadrant channel. However, it was observed that this end was incorrectly positioned – normally, the crimped cable end is also seated in the channel and cannot come out.

Example of incorrect assembly

Example of correct assembly

An examination of the failure showed that it resulted from progressive cracking due to fatigue. This mechanism began because of the incorrect assembly of the cable, which generated abnormal bending stress in line with from its crimped cable end.

Operation with broken cable

As long as the failed cable didn't block any mechanism, manual control is maintained without difficulty, since the automatic control path is transparent relative to the manual path.

However, based on the operation of the system as described earlier, if the pitch-up cable fails, the autopilot can no longer actuate the elevator to pitch up, though it can make it pitch down. Therefore, if the autopilot computer sends a pitch-up command, it sends a rotation command in the direction indicated to the servo. This rotation is not transmitted to the elevator due to the failure. However, after a certain number of servo rotations, it is possible[(2)] that the rotation movement becomes constrained, for example by the forming of a loop in the pitch-down cable, which becomes slack, or due to the pitch-up cable getting blocked in another elevator mechanism. Beyond a force threshold required for the servo to perform its rotation, the autopilot computer triggers the movement of the elevator trim to decrease this force.

The investigation was not able to determine with certainty the link between the appearance of the "AP PITCH TRIM" caution message and the system condition during the flight. However, it is highly probable that the caution message was linked to the trim movement by the autopilot for a period that was longer than the threshold of the caution message trigger.

Maintenance action

At the Paris Charles de Gaulle stopover, the maintenance technicians performed troubleshooting on the Maintenance Data Computer (MDC) concerning the FCC. No failures were recorded. They also performed an FCC operational test and then, three times, the elevator servo operational test (maintenance card 22-11-24-710-801).

This test consists of engaging the AP, giving it a pitch-up command, and checking the correct operation of the system by moving the elevator and displaying various messages on the PFD and EICAS displays. Similar checks are then performed with an AP input to pitch down.

The technician that performed the tests, as well as the copilot and two technicians present in the cockpit to perform another maintenance operation, confirmed that they saw the control column move and the indicator representing the position of the elevator move on the EICAS primary page.

However, system analysis showed that the elevator could not move to its maximum end of travel with the cable broken.

Several tests consisting of applying this maintenance card to a ready-to-fly aircraft were performed on operator and manufacturer premises. Each time, its application generated comments and sometimes questions.

For example, it was found that the card does not specify certain configuration actions required for its correct progress (activation of inertial measurement units).

[(2)] This behavior could not be confirmed due to lack of an appropriate test bench – an aircraft test could have caused major damage to the structure. However, it seemed a reasonable assumption to the various parties involved in the investigation, including Bombardier and Rockwell Collins.

An extract from the card is reproduced below:

> *(5) On the FCP, move the VS/pitch wheel to the UP position. Make sure that the conditions that follow occur:*
>
> *(a) On both PFDs, the command bars show a pitch−up command.*
>
> *(b) The elevator moves up.*
>
> *(c) When the elevator moves to the maximum position, the PFDs show the elevator mistrim yellow boxed letter E indication.*
>
> *(d) On the EICAS primary page, the caution messages AP PITCH TRIM and AP TRIM IS NU come on.*
>
> *NOTE: The caution message AP PITCH TRIM shows only when the stabilizer trim reaches its maximum end of travel.*
>
> *(e) The autopilot stays engaged.*

The card requires checking that the elevator moves. However, it does not say how the check should be performed: the operator can observe it through the movement of the elevator itself with the help of a colleague, or through the movement of the control column in the cockpit, or via the information on the elevator position provided by the EICAS primary page.

Likewise, the card indicates that a special indication (boxed letter E) should appear on the PDF when the elevator moves to the maximum position. However, this position was in fact not reached[3]. The indication appears despite the aforementioned.

Lastly, the "AP PITCH TRIM" caution message should appear during application of this card. Yet the caution message did not appear for two minutes. If the technician chooses to check the proper performance of the card using the EICAS page, he will see the continuous movement of the elevator trim and this will naturally reach the end of its travel, at which time the message in fact appears. If the technician chooses to interpret the elevator movement via the control column movement, it is possible he will not wait the two minutes during which nothing happens, this being apparently confirmed by the note indicating that the message only appears if the stabilizer reaches its stop.

Origin of incorrect assembly

The aircraft maintenance history was examined. No operations had been performed on the broken cable. The aircraft was delivered new to Brit Air.

The incorrect assembly therefore likely occurred during aircraft manufacture.

The vertical stabilizer is constructed by a subcontractor and delivered to Bombardier with its accessories installed, including the elevator cable, quadrant and servo assembly. Bombardier is responsible for mating the vertical stabilizer with the fuselage.

[3] This was observed during the various tests on aircraft of the same type: the indicator on the EICAS page is at roughly 75% of the maximum travel and it is possible to override the AP manually to allow the elevator to reach its maximum position. This behavior is due to the response of the auto-trim, which is triggered when a load threshold is reached on the elevator control path.

Once the assembly is completed, a functional test procedure is applied to perform the adjustments and functional tests. This procedure, as concerns the AP cables, is performed by two technicians. An independent inspection is performed by a third technician. The procedure requires checking the cable tension and ensuring that all cables and interface or stop mechanisms are correctly installed by drawing attention to certain types of assembly. It does not mention anything in particular regarding the positioning of the cable ends identical to those connecting the servo to the elevator quadrant.

Once the functional test procedure is completed, the closing procedure is performed according to the "assembly book." It provides, before closing the access doors to the assembly, a check, a double counter-check, and then an inspection by a quality inspector. The assembly book includes the sheets entitled "Checking points," drawing attention to certain specific installations such as for a lockwire, a latch in a tie rod end, tongue washers, or a flex cable. There is no sheet relating to the installation of the cable connecting the servo to the elevator quadrant.

As part of the investigation, interviews were undertaken with technicians and quality inspectors in charge of these assembly procedures and checks. The latter indicated that they have already identified similar cases of incorrect installation of the cable end in the quadrant[4] . An experienced quality inspector, in charge of the final check before termination, has indicated that during his career he had only encountered this situation once during the final check before termination.

[4]This type of assembly is present on several locations on the aircraft, some more accessible than others. The cases of incorrect assembly observed were not necessarily encountered at the end of the elevator autopilot control pitch-up cable.

The technicians and quality inspectors also indicated that such problems were reported to the quality department if they were encountered repeatedly, and that the quality department could thus take measures in conjunction with the supplier. However, no criterion for the frequency of occurrence of the problem exists for triggering such measures.

The technicians and quality inspectors involved in these assembly and checking operations take periodic update courses annually.

Cockpit video recording

During the second flight, during cruise, the crew recorded a video of the phenomenon using a mobile phone in order to provide more information on the problem to the maintenance service. They made this video available to the investigators.

This was useful because it allowed the display of the "AP PITCH TRIM" caution message on EICAS during the flight to be identified with certainty, compensating for the inadequate information provided by the flight recorders. In fact, the flight recorders indicated the triggering of a caution message but did not specify which message was displayed by the EICAS. An in-depth study based on the other parameters and on the knowledge of aircraft systems could have allowed assumptions to be made regarding the origin of the caution message but would probably not have confirmed this absolutely.

Image extracted from video provided by crew

Note: Likewise, as part of the investigation[5] into the near-collision that occurred on June 2, 2010 in the Bordeaux FIR (OLRAK point) between the Airbus A318 registered F-GUGJ operated by Air France and the Pilatus PC12 registered EC-ISH, the crew of the latter airplane chose to take photos of the instruments to explain the technical problem encountered to the manufacturer. They also made these images available to the investigators.

[5]The investigation report relative to this incident is available on the BEA website.

CONCLUSION

The servo pitch-up command cable broke near the aft quadrant of the elevator due to fatigue, the result of incorrect installation of the end of this cable in the quadrant channel. This incorrect installation most probably occurred during assembly of the elevator at the time of aircraft construction.

The failure did not have any significant consequences on the flight during which it occurred.

Neither did it have any significant consequence on manual control of the aircraft up to the flare during the third landing after it occurred. However, the hardening of the controls experienced during the flare could have occurred at any time during the flight and the risk associated with a loss of effective inputs on the flight controls was real during the flight.

In addition, the autopilot was significantly downgraded. This phenomenon was observed and indicated in the aircraft technical logbook during the two flights following the flight during which the failure occurred.

Following the notes made in the technical logbook after the first flight following the flight when the failure occurred, the maintenance operations performed did not highlight the flight control problem. It was following the second flight, during which stiffening of the controls was observed during manual control, that the problem was identified.

The stiffening of the elevator was probably due to the blocking of the cable in the servo mechanism, whose consequence was to limit the travel of the elevator aft quadrant.

LESSONS LEARNED

The checks performed during aircraft assembly generally allow detection of an incorrect installation such as the one that led to the event. This assembly problem is not unique, but the fact that it was not detected seems exceptional. However, the incident shows that the quality control system does not guarantee that non-detection of this incorrect installation will not occur again.

The case of the incorrect assembly identified through this event could be used to increase awareness of those persons involved concerning the risk generated by incorrect installation. This can be done, for example, through the skills training courses followed by these operators, or by using sheets that draw the operators' attention to certain specific points in the various documents used during the assembly process.

The application of maintenance task 22-11-24-710-801 should have made it possible to detect the problem on the flight control system. This was not the case. It could not be determined whether this failure was due to imprecision in the contents of the Task Card or incorrect application by the technician.

ACTIONS TAKEN BY THE MANUFACTURER

Following discussions with the BEA, Bombardier took the following actions in August 2011:

- ❒ Revised AMM Task 22-11-24-710-801;
- ❒ Revised Bombardier "Functional Test Procedure";
- ❒ Revised Aeronova "Cahier de Montage".

RECOMMENDATION

Note: in accordance with Article 17.3 of European Regulation (EU) 996/2010 of the European Parliament and Council of 20 October 2010 on the investigation and prevention of accidents and incidents in civil aviation, a safety recommendation shall in no case create a presumption of blame or liability for an accident, a serious incident or an incident. The addressee of a safety recommendation shall inform the safety investigation authority which issued the recommendation of the actions taken or under consideration, under the conditions described in Article 18 of the aforementioned Regulation.

The use of the video recorded by the crew was in fact useful to the investigation, by supplying information that is not easily available elsewhere. Likewise, photos taken by the Pilatus crew during the incident flight on June 2, 2010 provided data not recorded elsewhere.

The BEA has already recommended, on completion of various investigations[6], that ICAO consider the installation of protected image recorders on aircraft used for public transport flights. Investigation authorities from other countries have also made recommendations[7] on this subject.

ICAO is currently working with a view to adopting standards and recommended practices concerning the installation of image recorders. However, this work is not yet complete.

Consequently, the BEA recommends:

- ❍ **that ICAO continue its efforts to implement installation of flight image recorders on aircraft that undertake public transport flights. [Recommendation FRAN-2012-027]**

[6] Investigation into the accident on January 20, 1992 to the Airbus A320 registered F-GGED, investigation into the serious incident that occurred on November 23, 1997 to the MD83 registered F-GRMC, and investigation into the accident on July 25, 2000 to the Concorde registered F-BTSC.

[7] The United States investigation authority, as part of two recommendations issued on April 11, 2000 following several investigations; the United Arab Emirates investigation authority, as part of the investigation into the accident on February 10, 2004 to the Fokker F27 registered EP-LCA; the Greek investigation authority, as part of the investigation into the accident on August 14, 2005 to the Boeing B737 registered 5B-DBY; the United Kingdom investigation authority, as part of the investigation into the serious incident on October 22, 2005 to the Airbus A319 registered G-EUOB; the Russian investigation authority, as part of the investigation into the accident on July 8, 2006 to the Airbus A310 registered F-OGYP.