SERIOUS INCIDENT

Aircraft Type and Registration:	BAe ATP, SE-MAO
No & Type of Engines:	2 Pratt & Whitney Canada PW126 turboprop engines
Year of Manufacture:	1989 (Serial no: 2011)
Date & Time (UTC):	18 August 2020 at 0825 hrs
Location:	After departure from Jersey Airport, Channel Islands
Type of Flight:	Commercial Air Transport (Cargo)
Persons on Board:	Crew - 2 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	None
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	50 years
Commander's Flying Experience:	14,500 hours (of which 100 were on type) Last 90 days - 60 hours Last 28 days - 30 hours
Information Source:	AAIB Field investigation

Synopsis

During a short flight from Jersey Airport to Guernsey Airport, Channel Islands, the flight crew experienced difficult, but manageable, issues with roll control. The aircraft landed safely.

Despite extensive testing, no faults were identified that could have caused the event. The investigation did identify two minor issues with autopilot computer maintenance and testing. These have been addressed through safety action taken by the operator.

History of the flight

The aircraft departed from Jersey's Runway 26 at 0817 hrs for the short flight to Guernsey (the aircraft's track is shown in Figure 1), with the co-pilot as pilot flying (PF). It levelled at 2,000 ft amsl and tracked towards the Guernsey VOR (GUR), with an airspeed of around 200 KIAS. ATC had issued a right turn on to heading 340° when the crew experienced a "jolt" accompanied by a roll to the left, which was corrected by the autopilot. A second "jolt" disengaged the autopilot, generating a continuous 'cavalry charge' audio warning. The co-pilot silenced the warning and took manual control of the aircraft. She intended to continue turning right but found it difficult because the aircraft was "pushing to the left". She said "I'm just giving everything I have to just hold it steady"[1]. Her speech appeared

Footnote

1 CVR data was available for the flight.

calm with no evidence of physical strain, and she was able to comprehend the commander's instructions, with no need for him to repeat anything.

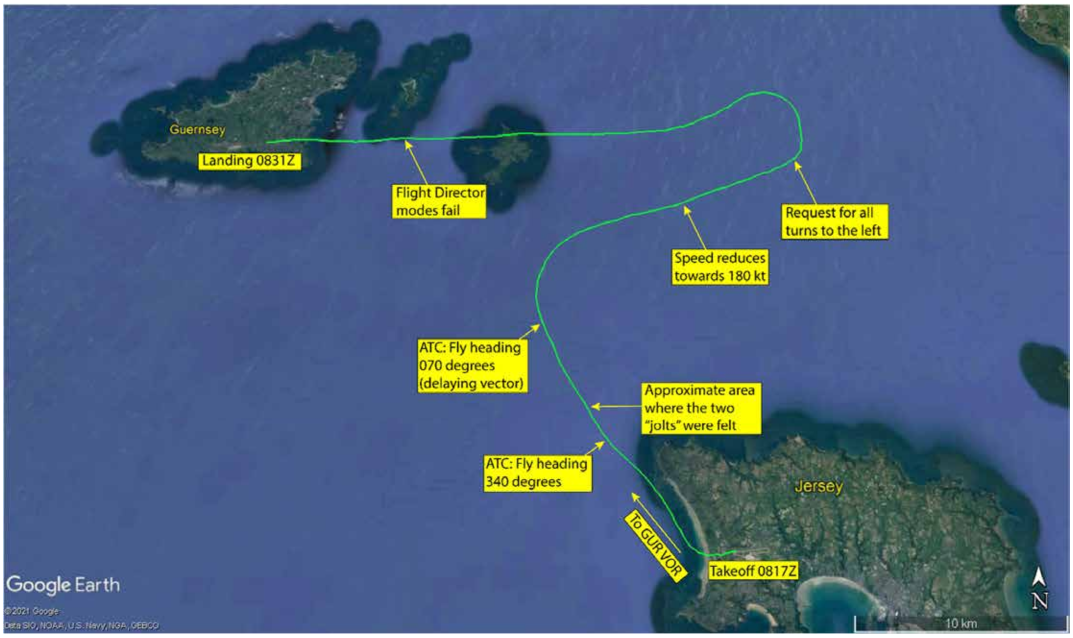

Figure 1

Aircraft's track during the incident flight

The commander transmitted "COULD YOU JUST GIVE US SOME DELAYING VECTORS, JUST FOR A LITTLE BIT, GOT A MINOR ISSUE WE NEED TO SORT OUT" to ATC. They issued a heading of 070°, taking the aircraft through Guernsey's Runway 27 centreline to the north. The crew slowed the aircraft to 180 KIAS which reduced the abnormal control forces.

When the aircraft was flying straight, the commander tried controlling it from his side but experienced the same forces. He subsequently described the aircraft as being "fully controllable but need[ing] a lot of right input". Both crew members agreed that the co-pilot would resume flying the aircraft, enabling the commander to manage the technical issue. The commander recalled that other indications around the flight deck appeared normal, and the flying control trims were indicating neutral positions.

The commander reported a "SLIGHT CONTROL PROBLEM, NOTHING MAJOR, NOTHING SERIOUS" to ATC and, for controllability reasons, requested left turns to establish on the ILS localiser[2]. He prepared the aircraft for a manually-flown ILS using the flight director[3], and advised ATC to expect a normal approach and landing. After operating the aileron trim in an attempt to alleviate the abnormal control forces, the co-pilot commented "I THINK THAT'S BETTER". The commander checked the co-pilot was content to continue as PF and led an approach brief, mentioning the ramifications of abnormal control forces in the event of a go-around.

Footnote

2 Localiser – the horizontal guidance element of an instrument landing system.

3 Flight director – a guidance aid presented on the attitude indicator which shows the aircraft attitude required to follow a specified trajectory.

The crew recalled descending out of cloud at around 1,500 ft amsl. After becoming fully established on the ILS, the flight director modes failed and could not be re-selected. The co-pilot continued flying the ILS using raw data[4], with the commander making standard callouts to assist with the flightpath. The aircraft landed at 0831 hrs and taxied to stand normally. The total flight time was 14 minutes.

After the aircraft's engines had been shut down, the co-pilot reported that the flying controls felt normal.

Additional information from the crew

The commander stated that, as a crew, they had spare capacity to perform additional actions. However, he determined that, because aileron control was achievable, it was unnecessary to carry out the *'Aileron control jam'* checklist[5] and, in the absence of any other abnormal indications, no other procedures were relevant. He prioritised making a prompt approach because of overall workload and in case the control difficulties worsened.

The co-pilot recalled that handling the aircraft on final approach "felt ok". She considered that that was because the aircraft was descending in a straight line at a slower airspeed, rather than because the fault had disappeared.

Meteorological information

Guernsey's weather report at 0820 hrs gave a wind of 9 kt from 200°, visibility 10 km or more, broken cloud at 900 ft agl, showers in the vicinity, temperature 18°C, and QNH 1010 hPa.

Recorded information

SE-MAO was fitted with a magnetic tape Flight Data Recorder (FDR), capable of recording 25 hours of flight data, and a solid-state Cockpit Voice Recorder (CVR) of 2 hours duration. Both units were successfully downloaded at the AAIB and covered the whole event. The recording on the tape-based FDR was of a good quality.

Geographic position was not recorded by the FDR but was obtained from radar recordings, an annotated version of this data is shown in Figure 1.

Figure 2 shows the incident flight, produced from the FDR data, with salient points included from the CVR.

Note that the aileron positions, as recorded by the FDR which uses a transducer mounted in each wing, are relative angular measurements and the calibration necessary to show the absolute position of each aileron has not been applied. Also, the FDR only records attitude signals from Attitude Heading and Reference Unit (AHRU) No 1.

Footnote

[4] Raw data – using the basic flight instruments.
[5] From the ATP *'Emergency & abnormal checklist'*, it involves pulling the aileron disconnect handle to isolate a jam present on either the commander or co-pilot's side of the system.

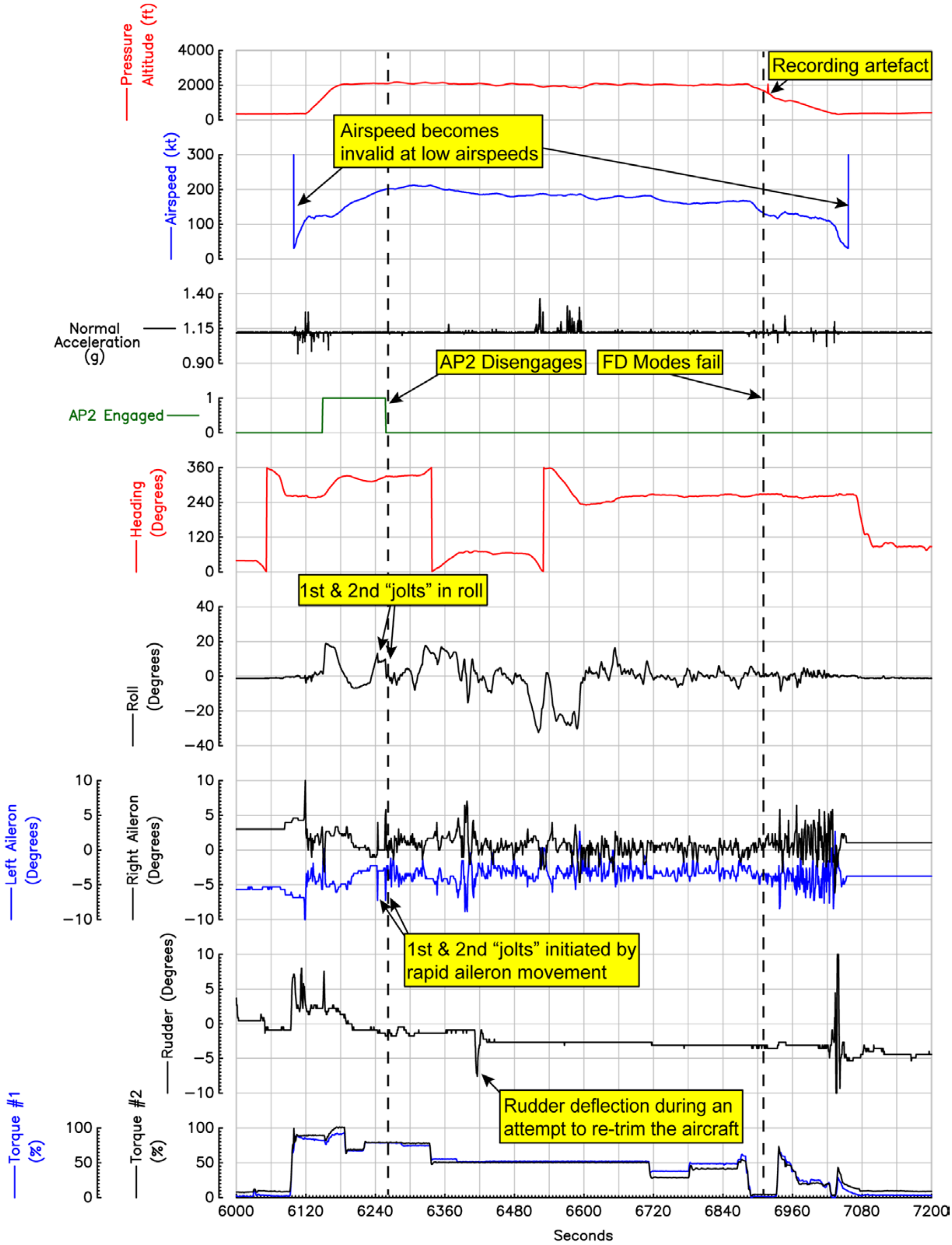

Figure 2

Salient recorded parameters

The recorded data (Figure 2) shows that the aircraft, at approximately 2,000 ft, and 200 KIAS in a right turn passing through a heading of 330°, rolled 5° sharply to the left. Shortly afterwards, the aircraft again rolled sharply to the left, this time by 10°. At that time, the No 2 autopilot, which was engaged, automatically disconnected and a continuous calvary charge was recorded on the CVR. Each sharp roll to the left was preceded by the rapid movement of both ailerons in the correct sense to initiate the observed roll. No fluctuations were observed in the normal acceleration values recorded by the FDR to indicate that the aircraft was experiencing any notable turbulence.

Aircraft information

General

The British Aerospace[6] ATP was derived from the Hawker Siddeley 748. The aircraft is a low-wing turboprop with a conventional tail configuration and two Pratt and Whitney PW126 engines, driving six-bladed variable-pitch propellers. ATPs were manufactured in a passenger configuration and some aircraft were subsequently modified to carry cargo.

SE-MAO

SE-MAO was manufactured in 1989 and had accrued 28,164 cycles and approximately 28,650 flying hours. It was originally configured for passenger transport but started cargo operations in 2007.

According to the operator, the last report of an in-flight fault with the autopilot was raised in June 2019 and this was successfully rectified after troubleshooting.

System descriptions

Autopilot

Automatic flight control is provided by two independent autopilots, only one of which can be engaged at any time. Each autopilot is a two-axis system (pitch and roll) with a yaw damper, and controls the aircraft using electrically-actuated servomotors (servos). A flight (autopilot) controller allows control of the autopilot functions and the selection of system 1 or 2. A simplified schematic of the autopilot interfaces that are discussed in this report is at Figure 3.

There are two autopilot computers that provide the necessary processing and outputs for the autopilot, flight directors and Standby Control System (SCS). The No 1 computer is installed in the forward avionics bay[7] and the No 2 computer is installed in the aft avionics bay. Both bays are beneath the cabin floor and are enclosed, with a hinged panel on the front to allow access to the equipment inside. Cooling air is provided by means of a plenum arrangement and the cooling air is sourced from the passenger (or cargo) cabin.

Footnote

6 BAE Systems (Operations) Ltd is the design Type Certificate holder.
7 The aircraft manuals refer to avionics crates as opposed to bays.

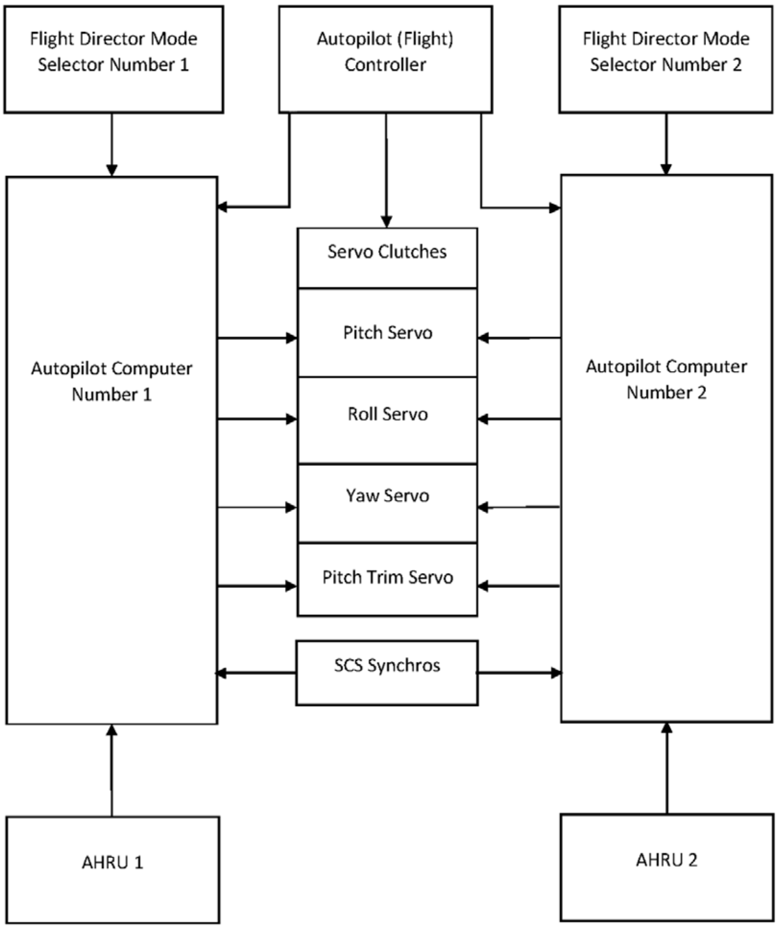

Figure 3

Simplified schematic of the autopilot interfaces

The electrically-actuated servo in each of the elevator, aileron and rudder controls converts the outputs from the autopilot computer into control surface movements. Each servo has a common gearbox driven by two independent motors, one for each autopilot system. An electromagnetic clutch fitted to each servo is energised when the autopilot is engaged. The clutches can be overcome if the autopilot fails to disengage.

When the autopilot is engaged, roll and pitch out-of-trim indicators in the cockpit deflect proportionally to the respective servo load current. If the current exceeds a pre-determined threshold for greater than 2 seconds in pitch or 12 seconds in roll, an amber TRIM light, which is adjacent to the out-of-trim indicators, illuminates (Figure 4). This provides a visible indication to the crew if the aircraft is significantly out-of-trim whilst the autopilot is engaged. When the autopilot is not engaged, electrical power is removed from the servos, so the out-of-trim indicators will remain neutral.

Figure 4

TRIM light and associated pitch and roll out-of-trim indicators
(highlighted in the orange box)

Autopilot disengagement

The autopilot can be manually disengaged by pressing the red autopilot disengage switch on either of the pilots' control wheels. This results in a one-second audible 'cavalry charge' warning.

The autopilot will automatically disengage if certain failures are detected, or pre-defined aircraft limits are exceeded. The automatic disengagement criteria include:

- Autopilot computer failure
- Attitude, heading or rate gyro signal invalid
- Servo short circuit
- Pitch attitude exceeds +/- 25°
- Servo clutch insulation breakdown
- ARINC[8] update failure
- Safety circuit operation

The autopilot safety circuit monitors the roll angle and normal acceleration. Automatic disengagement will occur if the roll angle from the active AHRU exceeds 35°, or the difference between the two AHRU roll outputs exceeds 5°. Disengagement will also occur if the normal acceleration is less than 0.4g or greater than 1.6g.

Footnote

8 ARINC refers to the data transfer standard used on the avionics data bus.

Automatic disengagement results in a continuous audible 'cavalry charge' warning, which can be cancelled by pressing either of the autopilot disengage switches.

Primary flying controls

The primary flying controls are operated directly from the control columns through a system of cables, rods and levers. Within the aileron (roll control) system the control wheels on the control columns are connected to each other by chains, sprockets and cable pulleys. The pulleys are connected by a continuous cable loop to quadrants under the left side of the flight deck floor and, from there, the cables are routed down the left side of the fuselage to a tension regulator / quadrant assembly and out to each aileron.

A synchro transmitter is mounted adjacent to each aileron. The right synchro provides a signal corresponding to the position of the right aileron to the SCS and the FDR, whereas the left synchro only provides a signal corresponding to the position of the left aileron to the FDR.

Both ailerons have a balance tab and the right aileron has a trim tab that is manually operated by the pilot using a trim wheel.

Aileron disconnection

The left control wheel is connected directly to its drive shaft and sprocket. The right control wheel comprises an automatic Aileron Control Disconnect Mechanism (ACDM), drive shaft and sprocket. The ACDM consists of a spring housing, 'C' spring and a synchro position transmitter. By applying sufficient force, it is possible for the right control wheel to rotate about its drive shaft, against the 'C' spring, and move independently of the left control wheel.

In the event of a restriction in the aileron primary controls, partial control can be retained by operation of the aileron disconnect unit, which isolates the left and right side of the aileron controls. The release unit is manually activated by pulling the aileron disconnect handle located on the centre console. This operates an electrical switch that energises a solenoid in the aileron release unit. The system cannot be reset in the air. Operation of the aileron disconnect handle also energises the synchro in the right control wheel, and movement of the control wheel against the 'C' spring sends continuous signals corresponding to the control wheel angle to the SCS. A force of 1.5 lb per degree of aileron movement is required to operate the aileron and movement of the control wheel is limited to 30 lbf, which equates to 20° of aileron movement. When operating in this mode, the position of the control wheel is not an indication of the displacement of the aileron.

Standby Control System (SCS)

The SCS is an emergency system that provides a means of operating the flying controls via the autopilot servos if the primary mechanical flying control circuits are jammed or severed. The SCS logic is controlled by a circuit board in the autopilot computer, so there are two independent systems. It is armed when electrical power is applied to the autopilot circuits, but it is inhibited whilst the autopilot is engaged.

Each SCS has independent channels to control the ailerons, elevator and the rudder. Each channel has a position input sensor (synchro) at the pilot's controls, which is continuously compared with a position feedback sensor (synchro) at the control surface. If the difference between the sensors exceeds a threshold value, and the autopilot is not engaged, the SCS will operate and the relevant servo will be driven to follow the pilot's control demands.

The SCS logic in the selected autopilot system continuously monitors the control inputs and feedback sensors. If the SCS operates, an ENGAGED light that corresponds to the active channel illuminates on the cockpit overhead panel. In addition, the amber STANDBY CONTROLS light illuminates on the central warning panel, the amber 'attention getters'[9] will flash, and an audible warning horn will sound.

Attitude Heading and Reference System (AHRS)

The AHRS provides aircraft attitude information using two independent AHRUs. When the autopilot is engaged, attitude information is sourced from the respective AHRU, which is installed alongside the autopilot computer in the avionics bay.

Aircraft examination

Initial examination and system testing was carried out under the supervision of the AAIB. There was no evidence of anything untoward when the aircraft was checked externally and, with electrical power switched off, the control wheels were free to operate throughout their entire range of movement without any restrictions. The ailerons, balance tabs, and aileron trim were all observed to operate normally.

The rear avionics compartment, where the No 2 autopilot is located, was checked and found to be dry. All the equipment in the compartment was found to be secure.

The aileron control system mechanical runs were visually checked and operated throughout their range of movement. No anomalies were identified, and the control cable tensions were confirmed to be correct.

The autopilot, SCS and AHRS were functionally tested and no faults were apparent, although the right aileron synchro required a small adjustment to bring it into the limits defined in the Aircraft Maintenance Manual.

The operator decided to remove the following components as a precautionary measure before the aircraft was returned to flight:

- Aileron servo (serial number 391)
- Autopilot computer No 1 (serial number 311)
- Autopilot computer No 2 (serial number 218)

Footnote

9 The 'attention getters' are flashing lights on the instrument panel glareshield. They provide a visual stimulus to the crew that they need to check the central warning panel.

- Autopilot controller (serial number 158)
- Accelerometer (serial number 152)

After reviewing the FDR data and the CVR audio recording, AHRU 1 (serial number 1124) and AHRU 2 (serial number 1281) were also removed. In the meantime, the aircraft had been returned to service and flown without further incident.

Equipment testing

Having reviewed the recorded data, and in consultation with the aircraft manufacturer and operator, the AAIB tested the following components as these would have been operational when the incident occurred:

- Aileron servo
- Autopilot computer No 2
- AHRU 2

Aileron servo

The maintenance policy requires autopilot servos to be overhauled every 4,500 flying hours. The aileron servo that was removed from SE-MAO was found to have exceeded this requirement by approximately 180 hours because the component operating hours had been erroneously reset to zero after a previous repair. The operator reviewed their fleet records and concluded this was an isolated occurrence. They amended their processes to ensure that component operating hours are only set to zero if an item is accompanied by a release certificate that states that the item has been overhauled.

The servo was tested and dismantled by the operator under the supervision of the Swedish Accident Investigation Authority; no anomalies were identified that could have caused or contributed to the incident.

Autopilot computer maintenance policy and test capability

There is no requirement for autopilot computers to undergo periodic testing or servicing, and there is no finite equipment life. If required, computers can be tested using an automated test set that is available at one overhaul agency in the UK. The AAIB established that the test set was no longer undergoing periodic calibration and the operator last returned a computer for testing in 2018. There was no way to recertify an autopilot computer as airworthy, so the operator has implemented a maintenance programme where four computers will be returned for testing on an annual basis.

For the purposes of this investigation, the uncalibrated test set was checked using an autopilot computer that was retained by the overhaul agency as a reference (control) unit. This computer was tested with no faults, and the results were compared with those that were previously obtained when the test set calibration was still valid. The results showed minimal change, indicating that the test set would be adequate for basic fault diagnosis.

Autopilot computer No 2

A label on the computer indicated that it was last tested in 2001 when, according to the operator's records, it had been sent for test / repair because of a problem relating to overshooting selected headings. On return to service it was stored for three years before being installed on SE-LGV. In March 2010, it was removed and stored for another six months. It was fitted to SE-MAO in September 2010 and the operator's maintenance history showed that it had been transposed with the No 1 computer several times whilst troubleshooting various autopilot anomalies.

The overhaul agency advised that the automated test is conducted at ambient (room) temperature and, if the test is passed, a computer could be certified as airworthy. The computer from SE-MAO was tested under the supervision of the AAIB and no faults were recorded.

The printed circuit boards (PCBs) were removed and visual examination found localised corrosion, white translucent staining, and an accumulation of detritus on three of them. The affected PCBs were associated with the SCS logic and autopilot servo operation (Figure 5).

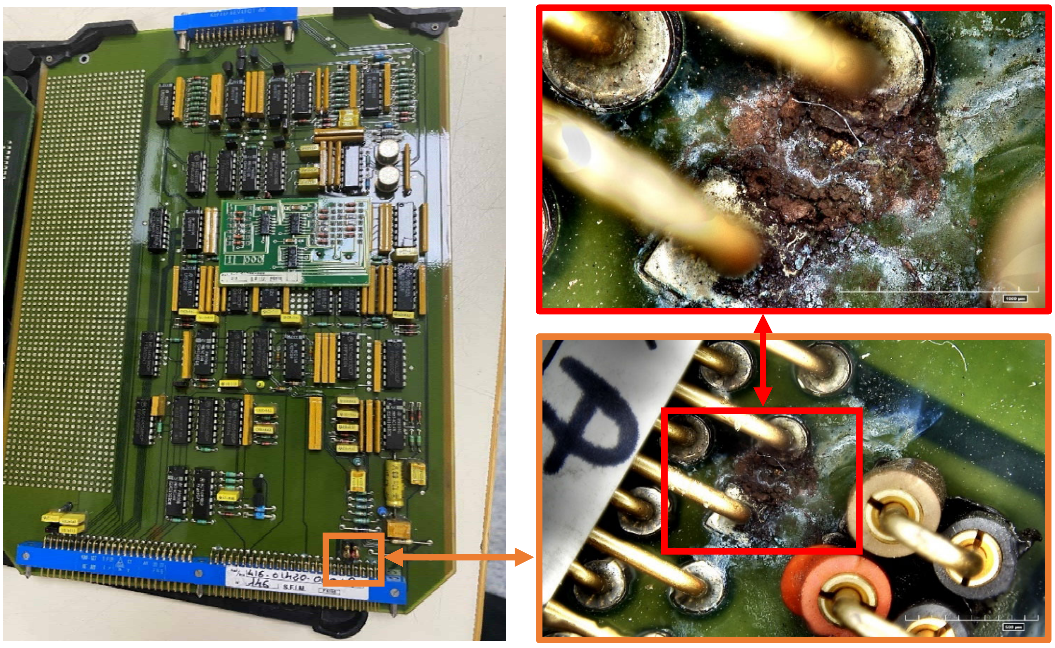

Figure 5

Corrosion, white staining and debris on one of the PCBs

The manufacturer responsible for the autopilot design reviewed photographs of the PCBs and stated that, in their opinion, the corrosion was probably caused by trapped flux, possibly left after a previous repair. They noted an area adjacent to one corrosion site where there was a visible difference in the conformal coating, Figure 6. The repair records from 2001 were no longer available so the detail of the work carried out is unknown.

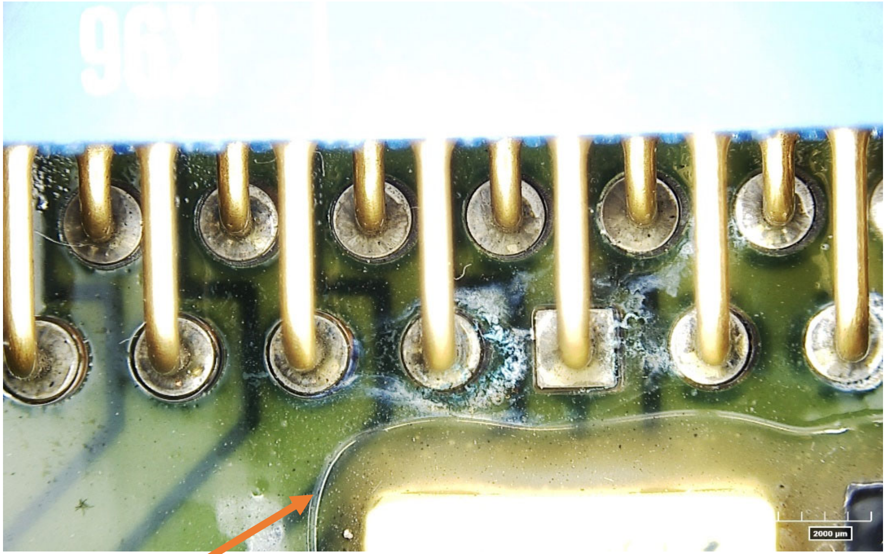

Figure 6
Discontinuity in the conformal coating

There was no requirement to check the internal condition of a computer returned for test or repair, so, under the normal test regime, the computer from SE-MAO would have been recertified as airworthy because it passed the requirements of the automated test.

Autopilot computer 1

The No 1 autopilot computer from SE-MAO was examined and there was no visible evidence of corrosion or debris on the PCBs.

AHRU

The No 2 AHRU was tested by an approved agency in the USA under the supervision of the National Transportation Safety Board (NTSB). The roll output was found to be slightly out of calibration (less than 0.2°), but this would not have caused or contributed to the incident with SE-MAO. The unit was disassembled and there was no evidence of Foreign Object Debris, visible corrosion or debris on the PCBs.

Type Certificate holder's assessment

The Type Certificate holder reviewed the flight data, test results, and the discovery of corrosion in the autopilot computer. They convened an internal design review, which concluded that the Type Design was satisfactory and continues to meet the required safety objectives. Consequently, no fleet action was deemed necessary.

Analysis

Initial "jolts" and autopilot disengagement

The FDR data showed that the two unexpected left rolls occurred whilst the No 2 autopilot was engaged. Both rolls were preceded by the ailerons deflecting and the aircraft manufacturer determined that the rate of aileron deflection matched the performance capability of the aileron servo. When the second roll occurred, the autopilot disengaged with an audible continuous cavalry charge. This indicates that the autopilot logic detected a condition that met the requirements for the autopilot to disengage automatically. It was not possible to determine the reason for the automatic disengagement because no faults were identified during the investigation and the autopilot computer does not record a 'fault log'.

Increased force when turning the control wheel to the right

The crew reported that it was harder to turn the control wheels to the right than to the left after the autopilot disengaged. They perceived that this force decreased as the aircraft slowed down, which might indicate an aerodynamic influence, but no anomalies were found in the aileron control system and the ailerons, balance tabs, and trim worked normally.

The flight data showed that the autopilot disengaged when the continuous 'cavalry charge' started, so the aileron servo clutch should have de-energised at that point. If the clutch failed to de-energise, the aileron servo would have remained connected to the control system, but any increased resistance caused by this should have been apparent in both directions of control wheel movement. The crew reported that the aileron out-of-trim indicator remained neutral after the autopilot disengaged, indicating that electrical power had probably been removed from the autopilot servo as designed.

When the servo was tested and dismantled, there was no evidence of any fault that could have caused or contributed to the incident, and the reason for the increased force to turn the control wheel could not be established.

Loss of the flight director

Flight director status and autopilot modes are not recorded on the FDR. No anomalies were identified during functional testing after the incident and the No 2 autopilot computer passed the automated test in accordance with the recertification requirements. The reason for the loss of the flight director modes during the approach to land at Guernsey could not be established. The operator reported that there have '*not been any significant autopilot issues*' since the aircraft was returned into service after the incident.

No 2 autopilot computer and corrosion

The No 2 autopilot computer was active when the incident occurred and would have been responsible for automatic flight control, the SCS, and the flight director functions. The computer passed the requirements of the recertification test which was conducted at ambient temperature.

When the PCBs were removed there was evidence of localised corrosion on the boards that control the autopilot servo and SCS logic. The overhaul agency and aircraft manufacturer advised that corrosion was not a known issue, and the manufacturer responsible for the design advised that it was probably caused by residual flux under the conformal coating, possibly from a previous repair. There is no requirement to check the internal condition of a computer that passes the automated test, so under the normal maintenance regime, the computer from SE-MAO would have been categorised as no fault found and recertified as airworthy.

Whilst the corrosion in the computer was worthy of note, there was no evidence to link it to this serious incident. The Type Certificate holder concluded that, with respect to the autopilot computer, the existing maintenance programme was appropriate to maintain continued airworthiness of the ATP fleet.

Crew workload management

The abnormal control forces experienced by the crew were significant and there was no checklist directly applicable. Therefore, the commander prioritised a prompt approach and landing, but did not declare an emergency to ATC.

The commander managed the increased workload effectively by providing support to the co-pilot as she flew the aircraft, whilst he led the decision making and communications. He described them having some "spare capacity", and the co-pilot reported the abnormal control forces improving as the aircraft slowed down. However, had the failure occurred in different circumstances, for example, at a higher airspeed, in less favourable weather conditions, and/or further away from a suitable landing airport, or had a go-around been required, then the resulting workload could have been considerably higher.

Conclusion

As the aircraft levelled-off at 2,000 ft and 200 KIAS, there were two uncommanded left rolls and the autopilot automatically disengaged. The crew found it harder to turn the control wheels to the right, but they maintained control of the aircraft and, although the flight director failed during the approach, they made an uneventful landing in Guernsey.

Extensive testing on the aircraft did not identify the cause, but the operator replaced several components as a precautionary measure. Subsequent component testing found no anomalies that could be definitively associated with the incident, although it did identify issues relating to equipment maintenance and testing. The operator has addressed these through appropriate safety action, and they reported that there been no recurrences since the aircraft returned to service.

Safety action

Since this event, the following safety action has been taken:

The operator has amended their processes to ensure that component operating hours are only set to zero if an item is accompanied by a release certificate that states that the item has been overhauled.

The operator has implemented a maintenance contract for its autopilot computers.

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